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Mineralization of ground water is the most prevalent factor in the degradation of ground water quality in the project area. Large quantities of ground water in each of the four states are undesirable for many uses because of excessive mineralization. Much of the mineralization of ground water is a result of natural processes. Some is caused by man's activities--irrigation, oil field brine disposal, and over-pumping of aquifers are common causes of mineralization. Usually the degradation is caused by an excess of total dissolved solids, but at some locations, specific toxic substances are also found in the ground water. Of the various forms of pollution of ground water caused by man's activities, nitrate is probably most prevalent in the project area.

A listing of conditions causing ground water pollution in the project area is included. ~~in the report.~~

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ARIZONA, CALIFORNIA, NEVADA & UTAH

by

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for the
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ABSTRACT

An investigation to determine the ground water pollution problems which exist in the states of Arizona, California, Nevada, and Utah was conducted. Data were obtained through an extensive review of the literature and through interviews with engineers, scientists and governmental officials concerned with water pollution in the four states of the project area.

Mineralization of ground water is the most prevalent factor in the degradation of ground water quality in the project area. Large quantities of ground water in each of the four states are undesirable for many uses because of excessive mineralization. Much of the mineralization of ground water is a result of natural processes. Some is caused by man's activities--irrigation, oil field brine disposal, and over-pumping of aquifers are common causes of mineralization. Usually the degradation is caused by an excess of total dissolved solids, but at some locations, specific toxic substances (of natural origin) are also found in the ground water. Boron and arsenic in toxic amounts have been found in ground water, especially in Arizona and Southern California. Of the various forms of pollution of ground water caused by man's activities, nitrate is probably most prevalent in the project area.

A listing of conditions causing ground water pollution in the project area is included in the report.

This report was submitted in fulfillment of project no. 16060 ERU, contract no. 14-12-919 under the sponsorship of the office of Research and Monitoring, Environmental Protection Agency.

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SECTION I

CONCLUSIONS

1. The general public and many public officials have inadequate knowledge of the factors affecting the quality of ground water and the limitations on ground water development.

2. All ground waters contain dissolved minerals. The natural leaching of soil by percolating waters in arid regions often causes natural accumulations of minerals which limit the usefulness of the ground water. The use of water by native vegetation increases the mineral content of the ground water. These and other natural processes are a major factor in the pollution of ground water in the project area.

3. Throughout the project area, there exist many water-bearing formations at considerable depth below the ground surface which contain minerals in high concentrations. Whenever these waters issue forth through deep oil well drilling or natural springs (often "hot"), they may represent an important source of ground water pollution.

4. It is impossible to adequately consider problems of ground water quality without also considering ground water quantity. Water of poor quality if in very limited supply may have little economic significance; and waters of good quality which are over-developed may bring connate brine or sea water into the fresh water aquifer, or affect the ground water in other ways.

5. There is an ever-increasing demand for water in the project area. Many of the ground water supplies have been developed beyond the "safe yield" limits and this often results in increased mineralization. Much of the water is also "re-used" several times with an accompanying decrease in quality. These trends will continue in the future with a continued degradation of the ground water.

6. Irrigation of agricultural lands provides great benefit to the economy and progress of the project area. This is not without "cost" in water quality, since the leaching process which maintains a necessary "salt balance" in the agricultural soil continually adds salt to the irrigation return flow, and thus to the ground water supply. Mineralization of the ground water, both from irrigation and natural sources is the greatest ground water quality problem in the project area.

7. Nitrates in the ground water are at dangerously high levels at many locations in the project area. The source of these nitrates is usually not known, but most likely sources are (a) solid waste land fills, (b) land disposal of various wastes, (c) fertilizer

applications, or (d) sewage effluent which gets into the ground water.

8. Boron is found in natural ground water at many locations in California, Arizona, and Nevada. It is a serious problem in some areas since it is toxic in relatively low concentrations to many plants.

9. Excessive concentrations of fluorides are found in ground water at a number of locations in the project area.

10. Iron, manganese and arsenic are present in ground water at a few locations in the area studies. They are usually of natural origin.

11. Phenols, gasoline and similar products have been found in the ground water at a few locations, and represent a constant hazard because of their widespread use. An underground gasoline leak in the Los Angeles area caused great damage to ground water over a rather large area. At latest report, the source had not been clearly determined even after exhaustive studies since the first detection in 1968.

12. Pesticides and bacterial pollution have not been known to travel appreciable distances in ground water, and have not been reported as representing a serious problem at any location in the study area.

13. Problems of ground water pollution vary greatly in magnitude and extent. For example, mineralization is a broad general problem throughout the entire arid region, whereas injection of a particular pollutant at a given point is usually a localized problem. Establishment of priorities for research or control measures should be carefully considered with this in mind.

SECTION II

RECOMMENDATIONS

1. Establish a national education and information program specifically oriented toward protection of ground water quality.

2. Update and extend the work of McGuinness, reported in USGS Water Supply Paper No. 1800, in order that quantitative determinations of ground water development potential may be available for the entire U.S.

3. Conduct investigations, similar to those reported herein, to identify the ground water pollution problems in all of the remaining parts of the U.S., with first efforts to be concentrated in the areas of greatest ground water development and greatest pollution hazard.

4. Initiate expended research efforts aimed at the solution of ground water pollution problems with emphasis on those problems most likely to achieve the most immediate and important impact. For detailed research recommendations, refer to Section VII herein.

5. In cooperation with the various states, develop and establish quality control criteria and enforceable standards to protect ground water quality throughout the U.S. In arid regions it is particularly important that the natural mineralization processes be recognized if the water resources are to be effectively used.

6. Recognizing the long-term disastrous results of accidental leakage such as the gasoline leak of 1968 in the Los Angeles area, the appropriate public officials should take steps to establish detection facilities and a disaster plan for use in the event of such a catastrophy at any location in the future.

SECTION III

INTRODUCTION

Ground water is used as a water supply by about two-thirds of the people in the United States. In many locations, ground water is the only economical source of water. In spite of the fact that ground water is used by many people, it is not well understood by the public, and the pollution problems connected with ground water are not understood very well at all. It is probable that many people cause pollution of ground water unknowingly, and consider the quality of ground water as resulting from natural causes. A considerable amount of ground water pollution is the result of natural phenomena which have been taking place over a long period of time. On the other hand, much pollution of ground water is the result of careless or deliberate acts of man.

Generally the pollution of ground water takes place slowly because the movement of the ground water is very slow and it often takes a long time to distribute a pollutant throughout a large volume of ground water. However, once the ground water is polluted it is difficult and time consuming to remedy the situation. For this reason, it is generally wise to prevent pollution of ground water rather than to remove it after it is already in the water. Recently a national magazine devoted one issue to the problems of ground water pollution (1) and evidence indicates that the ground water quality is deteriorating in many areas. Ground water pollution is a problem of national concern, and research and public action are needed to help preserve our ground water resources.

~~Whatever the cause of pollution, the ground water resource~~ may be rendered unfit for use if corrective measures are not taken. Corrective or remedial measures can only be effectively planned and evaluated if knowledge is available delineating the extent and kind of pollution which exists. This report is intended to provide such knowledge for the Southwestern part of the United States--the states of Arizona, California, Nevada and Utah. The report will also relate briefly to potential problems, which could develop in the future, and with recommendations for research related to the preventing or correcting of ground water pollution.

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SECTION IV

DESCRIPTION OF PROJECT AREA

The project area includes the states of Arizona, California, Nevada and Utah--the most arid part of the United States. Within the boundaries of the area are vast deserts, several large salt lakes, high mountain ranges and productive agricultural areas. The project area represents an area of 468,000 square miles, about 13% of the area of the United States. It includes the most populous state (California) and one of the least populous (Nevada). Ground water use in the project area is about 40% of the total for the United States.

Physiography

The project area is characterized by a wide variation in physiographic features. Dominating the area are several mountain ranges (including the Sierra Nevada, The Wasatch, and The Uinta Mountains), a large closed desert basin (known as the Great Salt Lake Basin), and the vast Colorado Plateau.

Using the classification of Thomas (2) who divided the U.S. into ten Ground Water Regions (consolidating the 21 Physiographic Regions of Meinzer (3), and the 24 Physiographic Regions of Fenneman (4)), it is seen that the study area includes areas classified in four of the basic Ground Water Regions:

(1) The Alluvial Basins
(2) The Western Mountain Ranges
(3) The Colorado Plateau
(4) The Columbia Plateau

It is noteworthy that these regions do not have a single closed boundary--especially is this true of the first two--but include areas at a number of locations, as dictated by the occurrence of the physiographic features which give them their name. Thus, the major mountain ranges in the study area; The Sierra Nevada, and The Wasatch, are classified as being in the Western Mountain Range Region. The extensive alluvial deposits at the base of these mountain ranges are in the Alluvial Basins Region. Actually, the Alluvial Basins Region includes the Coastal Plains of California, the Central Valley of California, most of the state of Nevada, all of the state of Utah west of the Wasatch Range, the Colorado Desert area in Southeastern California, and the Colorado Drainage (including the Gila River and its tributaries) in Arizona. The Colorado Plateau Region includes a large area in Northeastern Arizona and Southeastern Utah. Only a small part of the study area is included in the Columbia Plateau--a small area of volcanic deposits in Northeastern California. It is in the Alluvial Basins that most of the ground water supplies are found.

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The physiographic features have a pronounced effect upon the quantity and quality of ground water available. In the Alluvial Basins, the recharge potential is often more important than the extent and character of the alluvial deposit. Geologic conditions in the Western Mountain Region and in the Colorado Plateau have a great effect on the quality and quantity of ground water. For example, the escarpment along the southern boundary of the Colorado Plateau is known as the Mogollon Rim, and is the source of some rather large springs which contribute a considerable flow of water (which is of poor quality) to the Salt River, a tributary of the Gila River. At most locations in the Colorado Plateau, the potential ground water development is very limited, but at a few locations, because of faulting or other underground conditions, fairly good supplies of ground water may be developed.

Population

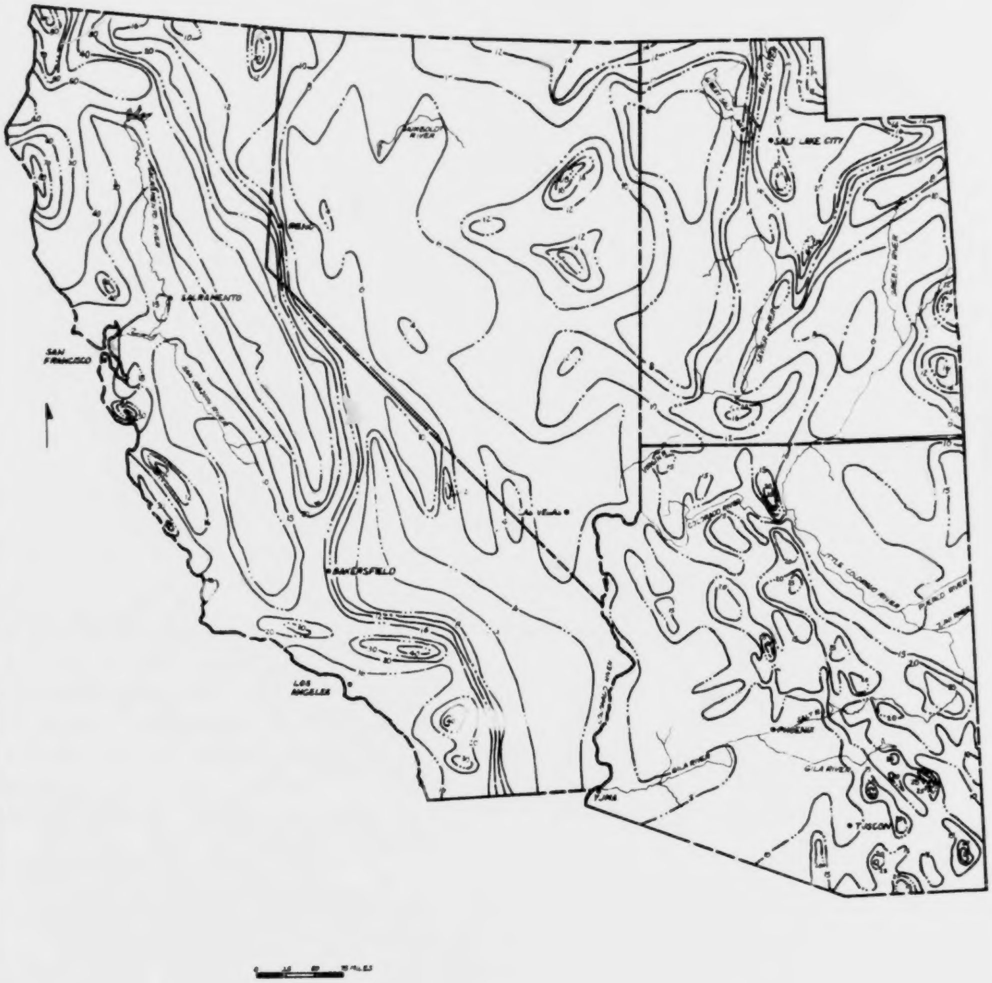
The study area includes several large urban areas with a high degree of development, and a large demand for water. It also includes vast unpopulated desert areas. The present population of the area is over 23 million people. The population by states is as follows:

	1960	1970
Arizona	1,302,161	1,752,122
California	15,717,204	19,715,490
Nevada	285,278	481,893
Utah	890,627	1,051,810

Rapid growth has occurred in each of the states since 1960 as shown by the above figures.

Climate

The climate of the project area is highly variable. Some of the mountain areas of California and Utah have relatively high rainfall, and at the higher elevations support alpine type of vegetation. In the North Coastal Basin of California, an annual precipitation of over 80 inches occurs at several locations. For the most part, however, the project area has an arid or semi-arid climate with very limited precipitation. Large areas of all four states receive less than 10 inches of precipitation annually. The average annual precipitation over the project area is shown in Figure 1. The sparse moisture condition of much of the area not only has a great effect on the water supplies and the ground water re-charge, but it also has a pronounced effect upon the characteristics of the soil mantle throughout the project area. In those areas where precipitation is high, the soluble minerals are leached from the soil, whereas in areas of low precipitation this has not occurred and ground waters are often salty--sometimes to the point of severely limiting their usefulness.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BAKERSFIELD
LOS ANGELES
YUMA
PHOENIX
TUCSON
GILA RIVER
LITTLE COLORADO RIVER
0 25 50 75 MILES

AVERAGE ANNUAL PRECIPITATION
IN THE PROJECT AREA

FIG. 1

The high summer temperatures, especially in the desert regions where natural drainage of the land is restricted, also has a detrimental effect on ground water quality. The desert regions of the south half of the project area experience temperatures above 100°F for a considerable part of each year. The average July temperature at many locations in Arizona and Southern California is over 90°F.

Geology

The significant geologic features of the project area from a ground water point of view might be briefly described as: (1) The Colorado Plateau, underlain with sedimentary rocks of variable characteristics but with limited ground water potential. (2) Vast deposits of alluvium along the Colorado River and its tributaries in Arizona and Southern California; along the Sacramento, and San Joaquin Rivers at the base of the Sierra Nevada Range; in the plains of the California Coastal Basins; and throughout the Great Basin area, especially in the area of the ancient Lake Bonneville. (3) Scattered formations of volcanic lava flows and ash beds, usually not of much significance in the ground water picture in the project area because of their erratic and discontinuous character.

A brief discussion of the geologic features of the project area follows below, particularly as related to the ground water potential from a quality and quantity stand point. Most of the material is digested from reports of the Water Resources Council (5, 6, 7, 8, 9, 10, 11, 12) the U.S. Bureau of Reclamation (13, 14), and the U.S. Geological Survey (15, 3), Thomas (2, 4), and Meinzer (3).

RECENT AND OLDER ALLUVIUM

Ground water occurs in geologic formations ranging from Precambrian to Recent. Most of the important ground water developments throughout the area of the project are in the alluvial deposits, many of which are of relatively recent origin. Some older deposits underlie the recent alluvium, particularly in the Colorado River delta along the lower reaches of the river in Arizona and California.

Outside of The Lower Colorado River drainage, the project area contains many different ground water basins. The basins are principally valley areas, surrounded in whole or in part, and underlain at depth, by virtually impermeable rock. The sedimentary fill of most groundwater basins is alluvium, consisting of permeable alluvial-fan and flood-plain deposits, and less permeable lake and swamp deposits.

Portions of many of the basins had at one time closed or restricted drainage, and lakes or playas formed in the central parts of the valleys. As a result, lakebed deposits, consisting of several hundreds of feet of clay, silt, sand, marl, and evaporites, occur within the older alluvium at many localities. It is sometimes difficult to differentiate between the older alluvium and the older indurated sediments, and much of the material ascribed to the older alluvium, beyond a depth of several hundred feet or below the lakebeds, may actually be the older indurated sediments. The higher yielding sands and gravels of the older alluvium are the principal sources of most of the ground water produced.

Beds of marine origin occur at shallow depths in some coastal basins, and permeable Quaternary basalt is the principal aquifer in several basins in the northeastern part of California. In some areas the effective depth of the ground-water reservoir is limited by the presence of tightly packed sediment of very low permeability; in other areas effective depth is limited by the presence of underlying saline water.

OLDER INDURATED SEDIMENTS

For the purpose of this report, the older indurated sediments arbitrarily include all of the sedimentary formations which underlie the older alluvium and rest upon the bedrock forming the floors and marginal uplands of the basins in southwestern Arizona. These deposits probably range in age from late Cretaceous to middle Tertiary, but may also include isolated bodies of older sedimentary rocks.

Relatively few wells fully penetrate the older indurated sediments; consequently, except in a few areas, very little is known about these formations. Most of the materials are probably similar lithologically to the lower portions of the older alluvium, but are distinguished from it by their greater degree of induration and by their faulted and tilted structure.

VOLCANICS

Volcanic formations of diverse ages are common in the project area, occurring principally as lava flows and associated ash beds. In some locations, these accumulations may be several thousand feet thick.

Volcanic materials are often highly fractured or porous, thus providing permeable zones capable of storing and transmitting ground water. As a rule, however, aquifers within volcanic formations are of an erratic and discontinuous character. Occasionally, a shallow well obtains water from highly fractured zones. Most wells, however, must penetrate an entire sequence in order to collect enough water for local use.

Available analyses indicate that water from volcanic formations is generally low in dissolved solids and that it is of good to excellent quality for most uses, but is usually limited in quantity to livestock or domestic uses.

PLATEAU SEDIMENTARY ROCKS

There are many permeable formations that serve as aquifers in the thick sequence of sedimentary deposits underlying the Plateau region of Arizona and Utah. These formations may be of great importance to a given community or to a particular stock or mining enterprise because in the broad expanse of area in the Colorado Plateau, water is extremely difficult to locate and develop. The total present and potential development of water, quantitatively, in this area is quite limited except in a few local situations.

Surface Water Supplies

It is not the purpose of this report to discuss the supplies of surface streams in the project area. It is important, however, to state simply that the ground water and surface waters are often closely related to each other. Many streams are fed in part by springs from ground water. Many ground water reservoirs are replenished by recharge from surface waters. In some locations, a surface stream may disappear entirely by infiltration into an alluvial deposit as the stream leaves the mountain reaches of its channel and enters the valley. In some areas, such as the Salt River Valley of Arizona, the quality of ground water may at times be of such a poor quality it cannot be used unless it is mixed with higher quality surface water.

In full utilization of our water resources, it will often be necessary to consider both surface and underground supplies used in conjunction with each other. For the purpose of this report, dealing with ground water pollution, the surface waters will not be considered further at this time.

Ground Water Resources

The importance of ground water pollution bears a direct relationship to the quantity of ground water available for development as well as the quantity presently being used from ground water. Consequently, in the paragraphs which follow, the ground water resources within the project area will be considered in some detail. Each of the four states will be discussed separately.

ARIZONA

The major ground water producing areas of Arizona are located in the alluvial deposits which are associated with the river systems in the Southwestern part of the state. The Northeastern two-fifths of the state has limited ground water potential because of the geologic conditions already described for the Colorado Plateau region. The areas of heaviest use generally coincide with the areas of greatest potential. As a matter of fact, considering Arizona as a whole, the ground water withdrawals exceed the recharge throughout most of the state, and water levels are, therefore, declining.

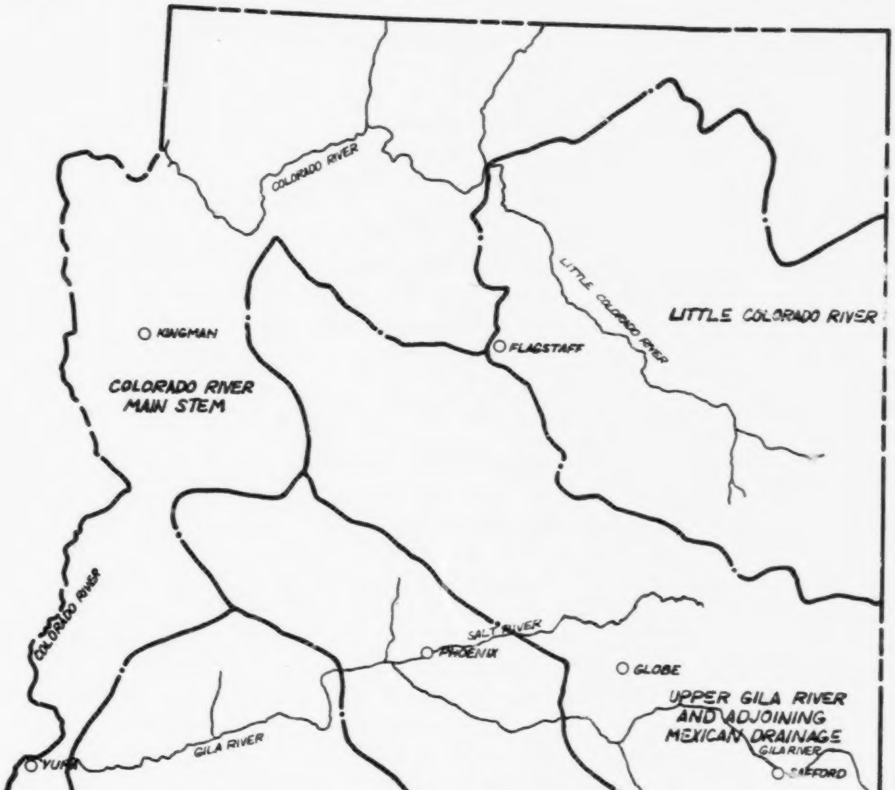
The U.S. Geological Survey, the U.S. Bureau of Reclamation, and the Arizona State Land Department have conducted detailed studies of ground water supplies in Arizona. For the purpose of this report, Arizona has been divided into five major hydrologic basins (Fig. 2), and various reports from the many separate ground water basins are grouped under these five basins herein. Some of the reports referred to are rather old and some of the studies on which the reports are based are more detailed than some of the others. For this reason, much of the quantitative information relating to either quantity or quality of water available is generalized. An attempt has been made to update material from the older reports by referring to some of the more recent ones such as those prepared by the U.S. Bureau of Reclamation in 1965 (13), the Pacific Southwest Interagency Committee of the Water Resources Council (9, 10), the Arizona State Land Department (16, 17, 18, and others), and the U.S. Geological Survey (15 and others). Figures on ground water use generally reflect conditions as of about 1962, and it should be borne in mind that the rates of withdrawal have probably in many instances increased during the period since 1962, especially in view of the years of severe drouth which have occurred in Arizona during this period.

The withdrawal of ground water varies from year to year, but it is estimated that there are about 5.7 million acre-feet of water being withdrawn annually from the ground water supplies of Arizona. Only about 50,000 acre-feet (or about one per cent of the state total) is taken annually from the Colorado Plateau and the transitional zone bordering on the Colorado Plateau. As pointed out in the previous sections of this report, the geologic formations in the Colorado Plateau and adjoining transitional zones offer a very limited ground water potential, and most of the wells which have been drilled have limited capacity, usually producing relatively small flows. On the other hand, the Alluvial Basins contain vast deposits of alluvial material with high permeability and extensive water storage potential. A brief discussion of the ground water supply potential for each of the five major hydrologic basins of the state is summarized in the paragraphs which follow.

Central Gila River and Adjoining Mexican Drainage

Of the five hydrologic basins in Arizona, this one contains the areas of greatest development and use of ground water, as well as the areas of greatest overdraft on the ground water with all of its attendant water quality problems. Water supplies in each of the ground water basins are discussed separately below.

Salt River Valley. The Salt River Valley contains the most concentrated agricultural and urban water-using area in Arizona. Surface and ground water provide irrigation water for more than 500,000 acres of land. It is a principal part of the largest area of ground water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CENTRAL GILA RIVER
AND ADJOINING
MEXICAN DRAINAGE
TUSCON
SAN PEDRO RIVER
0 5 20 30 MILES

HYDROLOGIC BASIN BOUNDARIES
IN ARIZONA

FIG. 2

overdraft in Arizona. More than 2,500 wells pump water from the ground water supply. The wells vary in depth from 300 feet to about 2,800 feet, and pump lifts range from about 200 feet to over 500 feet (13, 19, 20, 21, 22). Both surface water and ground water are inadequate to meet the needs of the area served, and the ground water levels are declining rapidly. Declines of ground water level were as much as 150 feet in 1950-60 (15), resulting in an average decline in some areas of 15 feet per year. Water importation is obviously necessary, unless pumping of ground water is curtailed. The use from ground water annually in the Salt River Valley was reported by USBR (13) as about 2,200,000 acre feet in 1962 but it has decreased since that time. In 1968 it was reported as 1,264,000 acre feet (23). It is used for irrigation and as a domestic supply for the Phoenix - Tempe - Mesa metropolitan area.

Lower Santa Cruz Area. This area borders the Salt River Valley on the South. It includes a large part of the Gila and Santa Cruz River Plain above the confluence with the Salt River. The deep alluvial deposits along the Gila and Santa Cruz Rivers provide a great ground water producing and storage area. However, in this basin, as in the Salt River Valley, the ground water is heavily over-developed. The annual use of ground water in this basin is about 1,150,000 acre feet. The combined use from ground water in this area and the Salt River Valley represents about 2/3 of the total ground water use of the State of Arizona. As in the Salt River Valley, ground water withdrawals greatly exceed recharge, and the vast underground water supply is being depleted by "mining". Declines in the water levels during the 1950-60 decade ranged from around 20 to more than 100 feet, with areas of greatest decline in the Southwestern part of the area, near Stanfield; and areas of least decline along the Gila River.

Upper Santa Cruz Area. This area includes the upper Santa Cruz River Basin in Pima and Santa Cruz Counties. The city of Tucson is located in this area. Ground water is pumped heavily for irrigation in a strip of land 1 to 2 miles wide along the Santa Cruz River north of Tucson, and for municipal and industrial use in the vicinity of Tucson. Water in this basin is taken from both the older and younger alluviums and, in minor amounts, from the older indurated sediments. In some locations, rapidly lowering water levels have virtually exhausted the usable ground water storage within the younger alluvium (13). Total estimated annual pumpage from this basin for all uses is about 210,000 acre-feet. Present withdrawals are greatly exceeding the available recharge, and ground water levels are declining throughout most of the basin. Wells are being drilled into the deeper sediments in search of a water supply. Some wells as deep as 2,500 feet have been reported, and considerable deep drilling is likely in the future. Studies of artificial recharge of the aquifers are underway (24, 25). Ground water hydrology of the San Xavier Indian Reservation, Southwest of Tucson is reported by Heindl and White (26, 27). Turner and others (28, 29, 30) have reported on the ground water conditions in the Santa Cruz Basin.

Avra-Marana Area. This area, located northwest of Tucson, has had extensive ground water development (31, 32). The ground water is produced primarily from sands and gravels in the older alluvium. Water levels have been generally declining, with an average of about 1 to 2 feet per year in the southern part of the area, compared with about 10 feet per year in the northern part, near Eloy. The ground water withdrawal in this area is about 175,000 acre feet per year, and the rate of withdrawal greatly exceeds the recharge.

Waterman Wash. Waterman Wash is a tributary of the Gila River, joining the Gila downstream from the Santa Cruz River. It is an area of relatively recent ground water development--which was in its early stages in 1950. Wells into both the older and younger alluvium pump large quantities of water for irrigation (19, 33, 34).

The pumpage of ground water increased rapidly to about 65,000 acre feet in 1961, then levelled off. In 1968 about 55,000 acre feet were withdrawn from the basin. Ground water levels continued to decline at about the same rate throughout the entire period 1956 to 1968, and it is evident that withdrawals exceed the recharge.

Gila Bend - Rainbow Valley Area. The ground water developed in this area is obtained mainly from the younger and older alluviums (35, 36). Some of the newer wells have been drilled into the older indurated sediments. The ground water levels have been steadily declining for a number of years, with wells near the river, where recharge occurs most readily, showing the least decline. Total annual withdrawal from the ground water in this area reached a peak of about 250,000 acre feet in 1960 and dropped to 150,000 in 1968. Ground water withdrawals exceed the recharge.

Harquahala Plains. The Harquahala Plains lie along Centennial Wash, which enters the Gila River from the north at Gillespie Dam. Development of this area has been rather recent, having only begun in 1951. By 1960, sixty irrigation wells were pumping a total of about 90,000 acre feet of water per year in some locations near the center of the cultivated area (37). The annual gross pumpage is now estimated at about 175,000 acre feet per year, and the withdrawal greatly exceeds the recharge, but there are probably several million acre feet of ground water in storage (Metzger 38).

McMullen Valley. The principal water bearing aquifer in this valley is the older alluvium. Well depths range up to 2,000 feet. Land development in this valley has increased greatly in recent years, accompanied by increased ground water development (Kam 39 and Briggs 40). Prior to 1950 the ground water use in the basin was about 3,000 acre feet per year, whereas the use in 1968 was about 107,000 acre feet. Water levels have declined, and it is evident that withdrawals of ground water are considerably in excess of the recharge.

Papago Indian Reservation. The Papago Indian Reservation is largely in Pima County, with small areas in Maricopa and Pinal Counties (41). It contains about 4,300 square miles--a vast area including most of the region between Tucson and Ajo, and south of Casa Grande all the way to the international boundary with Mexico. The deep alluvial fill in the valleys appears to be the main aquifer on the lands of the reservation. The fill consists of silt, sand and gravel, with varying amounts of clay, and varies in thickness from 350 feet to more than 1,000 feet (42, 43, 44, 45). The major water use on the reservation has been near Chuichu (12 wells reported in 1961) and near Papago Farms (7 wells reported in 1961). Declining water levels in the area of Chuichu, at the northeast corner of the reservation, has caused some wells to fail, which reduced the land under cultivation. According to the U.S. Bureau of Reclamation, the declines were caused by heavy pumping in the area just outside the reservation near Chuichu (13).

Ground water pumpage in the reservation area is estimated at about 10,000 acre feet per year. It is believed that there are a number of other valleys within the reservation where ground water supplies can be developed. The declining water levels near Chuichu reflect a local condition and do not indicate that the potential water development of the reservation has been exceeded.

Upper Gila River and Adjoining Mexican Drainage

This region covers a large area involving drainage into the Upper Gila River and the Willcox Basin (a closed basin) and the Douglas Basin which drains into Mexico. It also includes the transitional zone between the Mogollon Rim and the Salt River Valley.

San Pedro Basin. Both the younger and older alluvium are important aquifers in the San Pedro Valley. The younger alluvium varies in thickness up to 150 feet, and the older alluvium varies from a few feet to over 1,500 feet thick. A few wells derive water from the older sediments (46, 47, 48).

Water levels, especially in the younger alluvium, show considerable fluctuation but no long term trends are discernible. The total pumpage from the Basin in 1968 was estimated at 71,000 acre feet. Available information indicates that the recharge is approximately equal to the withdrawal.

Araviapa Valley. This valley contains alluvial deposits containing a fairly good water supply. Water is pumped to supplement stream diversions, with the amount varying from year to year. Three thousand four hundred acre feet were pumped in 1961.

San Simon Basin. The major aquifer of the San Simon Basin is the older alluvium. A thick "blue clay" divides the alluvial fill into an upper unconfined layer and a lower confined portion. Sand and fine gravel interbedded with thick lakebed deposits of silt and clay have been reported to a depth of 1,230 feet. These deposits are the major source of the waters of this basin (49, 50, 51, 52, 53). Pressures in the artesian aquifers have shown declines for many years, especially since 1952. East of Bowie, the pressure head has declined more than 100 feet since 1915, while near San Simon the decline has exceeded 80 feet, with 70 feet of this occurring since 1954. Annual pumpage by 1968 had exceeded 80,000 acre feet, and the accelerated rate of decline of artesian pressures indicates that withdrawals greatly exceed the basin recharge.

Duncan Basin. The Duncan Basin, in Arizona, is part of the Duncan-Virden Valley, which extends into New Mexico. It is part of the upper Gila River drainage basin. The major aquifer in the valley is the younger alluvium which lies in the channel and flood plain of the Gila River (54, 55). Irrigation wells range to about 300 feet depth, and the ground water table has been rising slightly since 1952 indicating that the recharge exceeds the withdrawal. Withdrawal has remained fairly constant for the ten years preceding 1969; and is estimated at 25,000 acre feet annually.

Safford Valley. The Safford Valley, located along the Gila River, has a major ground water aquifer located in the younger alluvium along the river (56). The younger alluvium ranges in thickness from a few feet along the periphery of the Gila River flood plain to about 110 feet near Safford. The older alluvium underlies the channel and flood plain deposits, and has much lower specific yield than the younger deposits. Wells in the younger alluvium are quite shallow--up to 120 feet--but those in the older alluvium range from 200 to 1,700 feet deep. Most of the wells in the older alluvium draw water from confined aquifers (57, 58, 59). Several deep wells, drilled into the older sediments as deep as 3,500 feet, have encountered hot confined waters.

Water levels fell in the area in the early 1950's to a low in 1957. For the years following 1957 there has been a general rise in the water levels, although there has been a decline in several of those years.

The ground water in this basin is pumped as a supplemental supply to the waters of the Gila River. The amount of withdrawal in years of low river flow may be as high as 160,000 acre feet, but in years of high river flow may be less than 100,000 acre feet. On the average, the withdrawals do not exceed the recharge.

Verde Valley. The Verde Valley flows off the Colorado Plateau and southward to the Salt River near Phoenix. The upper Verde Valley is located between the Black Hills and the Mogollon Rim. The principal aquifer within the valley is the Verde formation, which is commonly under confined conditions. Most wells draw water from the permeable limestones and sandstones of the formation. Some high capacity wells (up to about 2,000 gallons per minute) are prevalent in the valley. Specific capacities of wells drawing water from the limestone are generally low. More than 100 wells draw water from the Verde Formation. Further north, in the upper part of the drainage basin, near Sedona, wells generally 200 to 600 feet deep obtain water from sandstone of the Supai Formation, which still further north underlies the Coconino Sandstone (60). It is estimated that the annual pumpage from ground water in this valley is about 25,000 acre feet.

Chino Valley. Chino Valley, located about 20 miles north of Prescott, contains an artesian basin about 3 miles wide and 7 miles long. The main aquifer material consists of buried lava flows, volcanic ash and cinders, interbedded with older alluvium. Lonesome Valley is included in the area known as Chino Valley, though a ground water divide separates the two valleys (61). Groundwater in this area comes from the older alluvium. A total of about 18,000 acre feet is pumped from this valley annually, and the ground water level is declining slightly, indicating that the withdrawals slightly exceed the recharge.

Big Chino Valley. Big Chino Valley extends a distance of 30 miles or more to the northwest of Sullivan Lake and the town of Paulden. Ground water used in the valley is withdrawn from an alluvial fill consisting of lenticular silt and clay, sands and gravels, and frequently cemented conglomerate beds, inter-bedded with lava flows. Pumpage is usually about 20,000 acre feet per year (23). The water level has not declined over a period of years prior to 1969, and it appears that the withdrawals do not exceed the re-charge.

Willcox Basin. The Willcox Basin, located in Southeastern Arizona, has no exterior drainage. The major aquifer in the area is the older alluvium, in which both confined and unconfined waters occur (13, 62, 63). Thick clay sequences, containing gravel and sand lenses with water under pressure, are common within the alluvium. Surface and ground water move generally toward the Willcox Playa--the low area in this topographically closed basin. Ground waters in the Playa area are of poorer quality than those flowing toward the Playa. However, cones of depression created by heavy pumping have intercepted much of the groundwater which formerly flowed into the Willcox Playa, and continued heavy pumping will reverse the flow away from this area--bringing the water of poorer quality into many wells. Pumpage in 1967 and 1968 was estimated at 290,000 acre feet annually. This exceeds the annual recharge in the basin.

Douglas Basin. The Douglas Basin is the southern part of Sulphur Spring Valley which includes the Willcox Basin on the north and extends into Mexico on the south. In this basin, the major aquifer is the older alluvium, which is known to be at least 1,000 feet thick (19, 64). Depth to water in the basin was reported in 1962 to be generally less than 100 feet (13) and the water levels are generally declining. Gross pumpage has increased steadily. In 1957 the withdrawal from ground water was about 55,000 acre feet, and in 1969 about 120,000 (23).

Lower Gila River Valley

Wellton-Mohawk Area. In the Wellton-Mohawk area of the lower Gila River, the ground water is primarily in the younger alluvium (65, 66). Pumping of ground water for irrigation declined rapidly in the early 1950's and was replaced by surface water diverted from the Colorado River to the Wellton-Mohawk Irrigation Project. By 1957 pumping of ground water had virtually ceased. Subsequent recharge by return flows of Colorado River water caused water levels to rise to within a few inches of the land surface necessitating extensive drainage facilities. During 1962, sixty-one operating drainage wells pumped about 208,000 acre feet of ground water, causing an average decline of 2.7 feet in the water table. Pumping, for drainage purposes only, is now continued on a regular basis. Pumping in 1968 was 220,000 acre feet.

Palomas Plain - Dendora Valley. This includes the area along the Gila River drainage between the Gila Bend area downstream to the Wellton-Mohawk area (19, 67, 68, 69, 70, 35). This area has exhibited a steady increase in the amount of ground water use since 1958--increasing from about 30,000 acre feet in 1958 to about 125,000 acre feet in 1968. As with other ground water areas along the Gila River, this area has deep deposits of younger and older alluvium from which water is produced. Some wells as deep as 1,000 feet have been reported (13). No specific information is available regarding recharge and the balance between recharge and withdrawals. However, wells reported in 1969 (23) did not indicate general water table declines, and it is, therefore, not likely that the withdrawals have significantly exceeded the re-charge if at all.

Ajo Area. No published reports or description of the ground water potential are available for this area. According to the U.S. Bureau of Reclamation, 10,000 acre feet of water was used in this area in 1961 for industrial, domestic, and municipal uses (13).

Colorado River Drainage

Yuma Area. The Yuma Area includes South Gila Valley, Yuma Mesa, and Yuma Valley. The ground water comes from the younger and older alluvium. The ground water reservoir is reported to be wedge-shaped (13), ranging in thickness from about 210 feet at Laguna Dam to about 3,400 feet near San Luis. The upper portion of this reservoir consists of five deltaic deposits interbedded with coarse river channel deposits, and is 120 to 400 feet thick. The primary development of ground water is in the South Gila Valley. Elsewhere, a limited amount of ground water is pumped to supplement surface-water diversions from the Colorado River. Part of the ground water is pumped in order to drain agricultural lands of the area. This problem has been accentuated since the increase in irrigation of the lands of the Yuma Mesa Project of the U.S. Bureau of Reclamation. Ground water quality has also improved. The imported Colorado River water on Yuma Mesa, has been of higher quality than the existing ground water (see Brown and others 71, also Jacob 72, 73). The ground water levels have been rising since 1948. The amount of water pumped from the ground water has also been rising steadily--from 22,000 acre feet in 1945 to nearly 270,000 acre feet in 1968.

Ranegrass Plain. The Ranegrass Plain is part of a broad alluvial lowland interrupted by low mountains. The principal water bearing materials are in the older alluviums (16, 74). Ground water development in this area began in about 1951, and within a few years, the annual pumpage was about 20,000 acre feet. Water levels have declined slightly in most years since about 1955, and this general trend indicates that the pumpage is exceeding the recharge. The difficulty of locating good wells and the depth to ground water have presented more extensive development. Annual pumpage in 1968, up slightly from the immediately preceding years, was about 15,000 acre feet per year.

Bill Williams River Valley. The Bill Williams River drainage basin is located west of Prescott and drains directly into the Colorado River. According to Wolcott, Skibitzke and Halpenny (75) there is not much potential for ground water development in this valley. Most of the ground water is in the younger alluvium along the river, which has limited storage capability--between 10,000 and 15,000 acre feet. Their estimate of ground water use in 1951 was about 1,000 acre feet, but the U.S. Bureau of Reclamation in 1965 estimated total use in this valley of 10,000 acre feet per year (13).

Other Areas. There are a number of other isolated areas in the Colorado River Drainage where ground water development has occurred. Among these are three small valleys southwest of Prescott--Peeples Valley, Date Creek Valley, and Skull Valley--, the Kingman area, Big Sandy Valley southeast of Kingman, and the Chinle Valley in the northeastern part of the state. Total ground water use in these areas is estimated at 30,000 to 35,000 acre feet per year.

Little Colorado River Basin

This basin is sparsely populated. The communities of Flagstaff, Winslow, Holbrook and St. Johns are located in this basin. These communities and the agricultural areas near them use water from ground water sources, usually as a supplement to the surface water supplies. The principle aquifer in the basin is the Coconino sandstone, which is largely developed in the Mogollon slope country, south and west of the Little Colorado River. Production of sufficient water for irrigation purposes has been limited to areas in which the sandstone is highly fractured and jointed. However, there are numerous low-production wells that provide water for stock and domestic use. More than one water-bearing zone in the Coconino Sandstone has been recorded in some of the well logs. Irrigation wells capable of pumping 500 to 2,000 gallons per minute are found in the vicinity of Hunt, St. Johns, and Snowflake.

Ground water levels within the Coconino Sandstone have shown no significant decline; however, in local areas of heavy pumping, a few artesian wells have ceased to flow. No published estimate is available of the amount of water used from the ground water in this basin, but it is probably less than 20,000 acre feet per year.

CALIFORNIA

California uses more ground water than any other state of the nation. Most of the areas of the state have been developed beyond the "safe yield" of the ground water basins. However, the available ground-water storage capacity in California is vast. Although the storage capacity of all ground-water basins has not been determined in detail, it has been established that a capacity of more than 1,000 million acre-feet exists. Approximately 570 million acre-feet of that total is in the San Joaquin Valley above a depth of 1,000 feet, or above the base of those fresh-water-bearing sediments that do not reach a depth of 1,000 feet. Another 150 million acre-feet of storage exists in southern California--in the Mojave River Basin, Coachella Valley, and Los Angeles, San Bernardino, and Riverside Counties.

Not all of the billion acre-feet of gross storage capacity is usable. Usable storage capacity has been defined by Poland and others (76) in part as, "that reservoir capacity that can be shown to be economically capable of being dewatered during periods of deficient surface supply and capable of being resaturated, either naturally or artifically, during periods of excess surface supply. . ." To compute the total usable storage required the evaluation of such elements as permeability, economics of extraction and of recharge, and the suitability for use of waters of various qualities. Available data are inadequate for such an evaluation in much of the region, but it is currently estimated that the usable storage capacity of the ground-water basins in California totals more than 250 million acre-feet. These figures for gross and usable storage capacity of the ground-water basins are strikingly greater than the 77 million acre-feet of gross storage in surface reservoirs that are planned for development by the year 2020, and the 50 million acre-feet of active surface storage that is planned for the surface reservoirs of the future.

The proportion of usable storage that is presently occupied by ground water varies areally. In northern California the annual draft on ground water is replenished by recharge to the ground-water basins and a large proportion of the storage capacity is filled. In many of the basins in central and southern California, however, annual extractions exceed annual replenishment, and ground-water levels in a year of average precipitation and pumpage continue to fall. In the San Joaquin-Tulare Valley, for example, more than 70 million acre-feet of storage capacity is presently unwatered. In general, however, throughout the region a large proportion of the usable ground-water storage capacity is still occupied by economically obtainable water, although much of it is located in areas of little demand. Considered on the basis of major hydrologic basins, it is possible to make the generalization that all basins of the state are using ground water at a rate equal to or exceeding the "safe ground water yield" except the North Coastal Basin. There an estimated 100,000 acre-feet of water annually are still available for development. In all other basins of the state the waters are being "mined,"--or the withdrawals exceed the recharge.

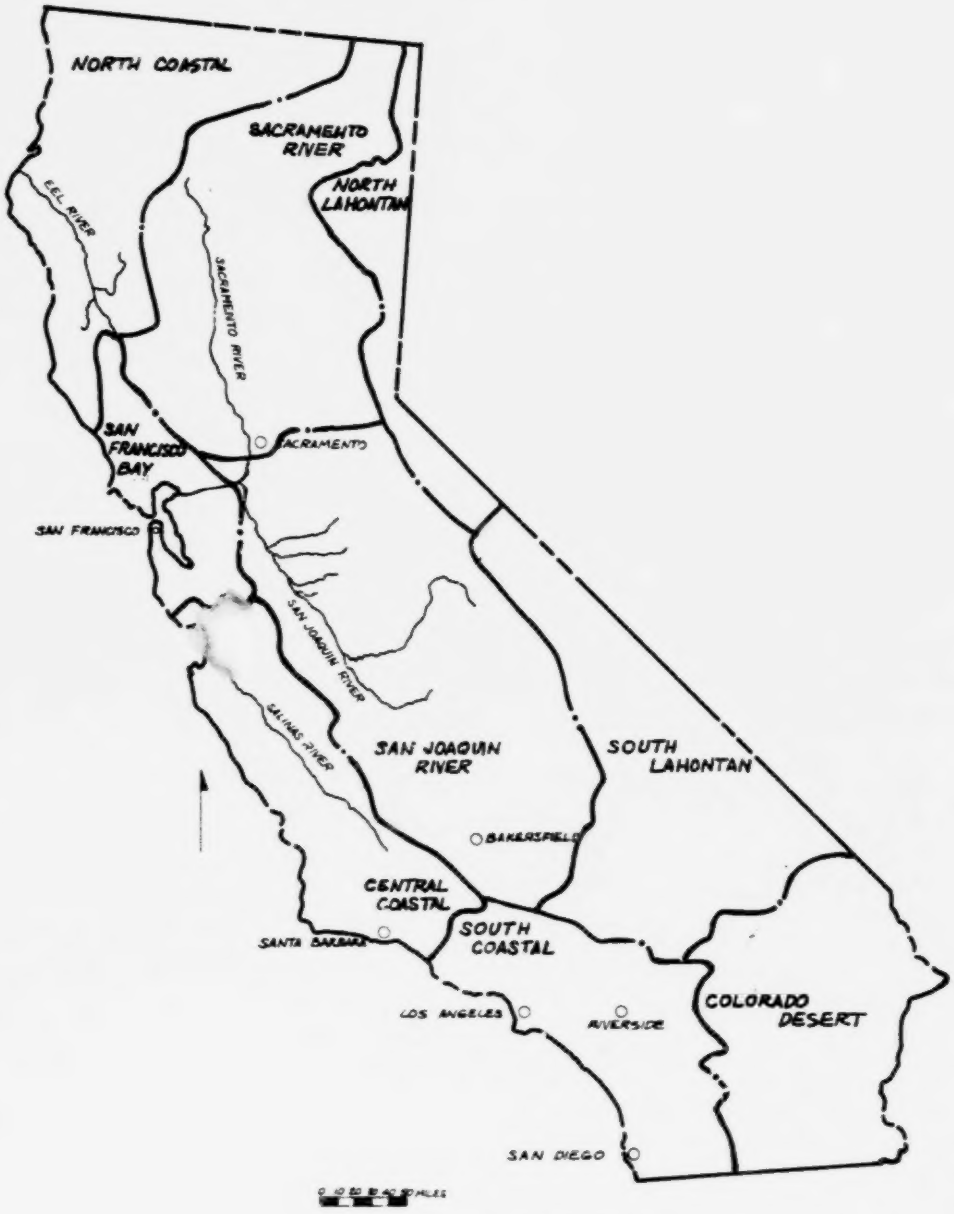
A brief discussion of ground water conditions in each basin is presented in the following paragraphs. The basins indicated are also the Ground Water Sub-Regions of the U.S. Geological Survey (77). Boundaries are indicated on Figure 3.

North Coastal Basin

Most usable ground water in this predominantly mountainous area occurs in widely scattered alluvium filled valleys and coastal plains. The alluvium consists generally of lenticular beds of unconsolidated to semiconsolidated clay, silt, sand, and gravel of Cenozoic age. The intervening mountainous areas are underlain by consolidated sedimentary, igneous, and metamorphic rocks mainly of Mesozoic age or older. These older rocks contain only small quantities of recoverable ground water and, therefore, are not considered further as a major source of ground water.

Thirteen valley-fill areas have been identified as significant sources of ground water. The total area of all 13 valleys is about 1,300 square miles. The water-bearing deposits range in thickness from 50 to 15,000 feet. Depending on local conditions, recharge infiltrates at rates of less than 1-1/2 feet per day to more than 10 feet per day in the upper part of alluvial fans, in stream channels, and in some areas underlain by volcanic rocks. The maximum measured depth to water in the water-bearing deposits is 185 feet. In several valleys there are flowing wells.

Total storage capacity of the valleys for which determinations have been made is nearly 1,000,000 acre-feet, of which about 700,000 acre-feet is considered usable (78). Limiting factors are the possibility of sea-water intrusion and aquifer materials of low permeability. Ground water temperature generally ranges from 50°F to 70°F, but locally is as low as 43°F and as high as 178°F. Total ground water use in this basin is estimated to be about 150,000 acre-feet per year. This is about 100,000 acre-feet less than the safe yield of this basin (5). Some characteristics of the North Coastal Basin are given


NORTH COASTAL
SACRAMENTO RIVER
NORTH LAHONTAN
EEL RIVER
SACRAMENTO RIVER
SAN FRANCISCO BAY
SACRAMENTO
SAN FRANCISCO
SAN JOAQUIN RIVER
SALINAS RIVER
SAN JOAQUIN RIVER
SOUTH LAHONTAN
BAKERSFIELD
CENTRAL COASTAL
SANTA BARBARA
SOUTH COASTAL
LOS ANGELES
RIVERSIDE
COLORADO DESERT
SAN DIEGO
0 10 20 30 40 50 MILES

HYDROLOGIC BASIN BOUNDARIES
IN CALIFORNIA

FIG. 3

in Table 1.

San Francisco Bay Basin

Most usable ground water in the predominantly mountainous San Francisco Bay Basin occurs in small scattered alluvium-filled valleys and in larger basins tributary to San Francisco Bay. The alluvium consists generally of lenticular beds of unconsolidated to semiconsolidated clay, silt, sand, and gravel of Cenozoic age. The intervening mountainous areas are underlain by consolidated sedimentary, igneous, and metamorphic rocks mainly of Mesozoic age. These older rocks contain only small quantities of recoverable ground water and, therefore, are not considered further as a major source of ground water.

In the San Francisco Bay Basin, eighteen valley-fill areas have been identified as significant sources of ground water. The total area of the eighteen valleys is about 2,000 square miles. The water-bearing deposits range in thickness from about 100 to 2,000 feet. Depending on local conditions, recharge infiltrates at rates of less than 1-1/2 feet per day to more than 10 feet per day in the upper part of alluvial fans and in stream channels. The maximum measured depth to water in the water-bearing deposits is 374 feet. In several valleys there are flowing wells.

Total storage capacity of the 14 basins for which determinations have been made is nearly 4,500,000 acre-feet. The usable storage capacity of the five basins for which determinations have been made is nearly 1,200,000 acre-feet (79). Limiting factors are salt-water intrusion, aquifer materials of low permeability, and water of poor quality. Ground-water temperature generally ranges from 50°F to 75°F, but locally is as high as 140°F.

Safe ground-water yield for the entire San Francisco Bay Basin is estimated to be 300,000 acre-feet per year; an annual overdraft estimated to be 70,000 acre-feet exists (5). Some characteristics of the San Francisco Bay Basin are given in Table 2.

Central Coastal Basin

Most usable ground water in the predominantly mountainous Central Coastal Basin occurs in alluvium-filled valleys and coastal plains, and in deeper aquifers of Quaternary and Tertiary age. The intervening mountainous areas are underlain by consolidated sedimentary, igneous, and metamorphic rocks, mainly of Mesozoic age. These older rocks contain only small quantities of recoverable ground water and, therefore, are not considered a major source of ground water.

In the Central Coastal Basin, 24 areas have been identified as significant sources of ground water. The total area of the 24 valley areas is about 3,500 square miles. The water-bearing deposits range in

Table 1 Principal ground-water basins in the North Coastal Basin (78)

Sub-Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (°F)	Range of dissolved solids (ppm)
Smith River Plain	70	100,000	75,000	53-67	33-175
Klamath River Valley	525	(a)	(a)	43-178	82-833
Butte Valley	475	(a)	(a)	(a)	109-1890
Shasta Valley	340	(a)	(a)	57-81	160-4870
Scott River Valley	85	400,000	300,000	44-65	29-417
Hayfork Valley	6	(a)	(a)	58-63	194-2760
Hoopa Valley	8	(a)	(a)	(a)	(a)
Eureka Plain	230	150,000	125,000	52-62	112-1090
Round Valley	25	230,000	150,000	57-62	116-392
Laytonville Valley	7	25,000	12,000	60-70	66-472
Little Lake Valley	17	50,000	40,000	57-67	70-522

(a) Not Determined.

Table 2 Principal ground-water basins in the San Francisco Basin (79)

Sub-Basin	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (^{o}F)	Range of dissolved solids (ppm)
Potter Valley	13	10,000	(a)	64-66	140-1020
Ukiah Valley	65	35,000	(a)	55-60	100-1030
Sanel Valley	10	20,000	(a)	(a)	143-327
Alexander Valley	35	50,000	(a)	63-64	220-1320
Santa Rosa Valley	150	1,000,000	(a)	60-89	93-427
Healdsburg Area	30	70,000	(a)	66	87-410
Petaluma Valley	127	208,000	(a)	63-64	255-4300
Napa Valley	230	300,000	(a)	52-110	118-11700
Sonoma Valley	150	180,000	(a)	64-140	135-2800
Suisun-Fairfield Valley	259	226,000	40,000	52-81	155-5600
Clayton Valley	30	180,000	80,000	(a)	212-692
Ygnacio Valley	32	200,000	50,000	(a)	715-2330
San Ramon Valley	31	(a)	(a)	(a)	(a)
Castro Valley	4	(a)	(a)	(a)	(a)
Santa Clara Valley	584	1,580,000	783,000	65-74	203-3220
Livermore Valley	170	400,000	200,000	64-67	304-4814
Sunol Valley	20	(a)	(a)	(a)	(a)

(a) Not Determined.

thickness from about 200 to 4,000 feet. Depending on local conditions, recharge infiltrates at rates of less than 1-1/2 feet per day to more than 10 feet per day in the upper part of alluvial fans and in stream channels and at the outcrops of the deeper aquifers. The maximum measured depth to water in the water-bearing deposits is 568 feet. In several valleys there are flowing wells.

Total storage capacity of the 16 basins for which determinations have been made is more than 20,000,000 acre-feet. The usable storage capacity of the 18 basins for which determinations have been made is more than 7,600,000 acre-feet; the limiting factors are sea-water encroachment and high pumping life (80). Ground-water temperature generally ranges from 55° to 75°F.

Safe ground-water yield for the entire Central Coastal Basin is estimated to be 900,000 acre-feet per year; an annual over-draft estimated to be 70,000 acre-feet exists (5). Some characteristics of the Central Coastal Basin are given in Table 3.

South Coastal Basin

Most usable ground water in the predominantly mountainous South Coastal Basin occurs in alluvium-filled valleys and coastal plains and in deeper aquifers of Quaternary and Tertiary age. The intervening mountainous areas are underlain by consolidated sedimentary, igneous, and metamorphic rocks, mainly of Mesozoic age. These older rocks contain only small quantities of recoverable ground water and, therefore, are not considered a major source of ground water.

In the South Coastal Basin, 44 areas have been identified as significant sources of ground water. The total area of the 44 valley areas is about 3,000 square miles. The water-bearing deposits range in thickness from about 50 to 2,500 feet. Depending on local conditions, recharge infiltrates at rates of less than 1-1/2 feet per day to more than 10 feet per day in the upper part of alluvial fans and in stream channels and at the outcrops of the deeper aquifers. The maximum measured depth to water in the water-bearing deposits is 799 feet. In several valleys there are flowing wells (81).

Water in storage (in 1965) in the basins for which determinations have been made totals nearly 100,000,000 acre-feet. The usable storage capacity was not determined for the largest basins but where determined, is more than 800,000 acre-feet; the limiting factors are possible sea-water intrusion, thin alluvial material, and locally, high pumping lift. Ground water temperature ranges from about 55° to 90°F, but locally is as high as 164°F (5).

Safe ground-water field for the entire South Coastal Basin is estimated to be 1.6 million acre-feet per year. There is no over-draft in the basin as a whole; while over-draft occurs in local areas, it is

Table 3 Principal ground-water basins in the Central Coastal Basin (80)

Sub-Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (^{o}F)	Range of dissolved solids (ppm)
Soquel-Aptos area	100	(a)	(a)	65-74	300-600
Pajaro Valley	142	Annual safe yield	21,000	60-66	255-759
Gilroy-Hollister Valley	348	932,000	800,000	65-69	276-2560
Salinas Valley Pressure area	192	(a)	(a)	59-74	251-3008
Salinas Valley eastside unit	132	690,000	412,000	(a)	(a)
Salinas Valley forebay and Arroyo Seco cone	305	2,380,000	900,000	(a)	(a)
Upper Salinas Valley	82	(a)	(a)	(a)	(a)
Paso Robles	907	6,800,000	1,700,000	(a)	(a)
Cholame Valley	22	(a)	(a)	(a)	(a)
San Antonio River Valley (Lockwood Valley)	93	1,000,000	500,000	(a)	(a)
Carmel Valley	12	(a)	(a)	60-75	324-767
Morro Bay Valley	17	112,200	14,700	(a)	(a)
San Luis Obispo Valley	15	67,000	10,000	(a)	(a)
Pismo Creek Valley	12	30,000	5,000	(a)	(a)
Arroyo Grande Valley (Including Nipomo Mesa)	45	380,000	140,000	(a)	(a)
Santa Maria Valley	206	2,000,000	1,000,000	57-65	234-3200
Cuyama Valley	229	2,100,000	400,000	65-70	400-5000
San Antonio Creek Valley	86	1,200,000	300,000	60-65	306-3045
Santa Ynez River Valley	206	2,000,000	1,000,000	57-75	400-11000
Goleta Basin	16	180,000	17,000	62-70	738-1400
Santa Barbara Basin	15	(a)	281,000	(a)	(a)
Carpinteria Basin	12	140,000	19,000	63-67	437-795
Carrizo Plain	269	400,000	100,000	(a)	(a)

(a) Not Determined.

compensated by artificial recharge in other areas. Some characteristics of the South Coastal Basin are given in Table 4.

San Joaquin Basin

Nearly all usable ground water in the San Joaquin Basin occurs in the alluvium-filled San Joaquin Valley. The aquifer system throughout the entire San Joaquin Valley is an integrated system.

The San Joaquin Valley has a total area of more than 13,000 square miles. The water-bearing deposits are as much as 3,500 feet thick. Recharge infiltrates at rates of less than 1-1/2 feet per day to about 3 feet per day over most of the valley floor and particularly on the east periphery of the valley. The maximum measured depth to water in the valley is 842 feet. The aquifer system of approximately 5,000 square miles in the west and central part of the basin is under artesian pressure.

Total storage capacity of the San Joaquin Valley is 93 million acre-feet. The usable storage capacity is 80 million acre-feet; low permeability in some areas is considered a limiting factor. Ground-water temperature ranges from about 45° to about 105°F (82).

Safe ground water yield for the Basin is estimated to be 6,550,000 acre-feet per year. There is a great over-draft from this basin--estimated to be 2,500,000 acre-feet annually (5). See Table 5 for details.

Sacramento Basin

Most usable ground water in the predominantly mountainous Sacramento Basin occurs in alluvium-filled valleys and in volcanic rocks of Quaternary and Tertiary age. In this sub-region 21 areas have been identified as significant sources of ground water. The total area of the 21 valley areas is about 6,150 square miles, 5,000 of which is occupied by the Sacramento Valley. The water-bearing deposits range in thickness from about 100 to 2,700 feet. Depending on local conditions, recharge infiltrates at rates of less than 1-1/2 feet per day to more than 10 feet per day in the upper part of alluvial fans and in stream channels. The maximum measured depth to water is 306 feet. In several valleys there are flowing wells.

Total storage capacity of the 17 basins for which determinations have been made is nearly 55,000,000 acre-feet, of which more than 33,000,000 is in the Sacramento Valley. The usable storage capacity in the Sacramento Valley is 22,000,000 acre-feet; the limiting factors are aquifer materials of low permeability, water of inferior quality, and economic considerations (83). Ground-water temperature generally ranges from 55°F to 75°F as shown in Table 6.

Table 4 Principal ground-water basins in the South Coastal Basin (81)

Sub-Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (°F)	Range of dissolved solids (ppm)
Ojai Valley	13	76,000	26,000	64-69	490-2189
Ventura River Valley	12	20,000	5,000	60-69	327-3410
Santa Clara River Valley and Oxnard Plain	460	15,600,000	(a)	61-77	278-33488
Acton Valley	13	40,000	16,000	(a)	324-584
Los Angeles-San Gabriel River Hydrologic Unit	505	29,360,000	(a)	55-89	144-34754
San Fernando Valley	205	3,400,000	(a)	56-96	222-2128
San Gabriel Valley	202	10,440,000	(a)	62-86	107-1004
Upper Santa Ana Valley	653	16,660,000	(a)	52-100	60-1900
Orange County Coastal Plain	357	15,800,000	(a)	57-164	138-36472
Cajalco Valley	2.5	(a)	(a)	(a)	(a)
Elsinore Valley	10	27,000	(a)	(a)	(a)
San Jacinto Valley	246	6,110,000	(a)	68-85	278-3914
Bear Valley	37	65,700	22,350	(a)	(a)
San Juan Valley	13	655,000	8,000	59-95	285-3914
San Mateo and San Onofre Valley	6	20,500	20,500	66-69	440-935
Santa Margarita Valley	32	525,000	525,000	64-85	230-2200
San Luis Rey Valley	37	240,000	50,000	64-74	83-14270
Warner Valley	44	550,000	55,000	69-129	156-418
Escondido Valley	16	24,000	12,000	64-81	256-6934
San Diego Coastal Drainage	78	310,000	98,800	61-96	164-22842

(a) Not Determined.

Table 5 Principal ground-water basins in the San Joaquin Valley (82)

Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (^oF)	Range of dissolved solids (ppm)
San Joaquin Valley	13,500	93,000,000	80,000,000	45-105	64-10,700
Panoche Valley	50	(a)	(a)	(a)	(a)
Squaw Valley	8	(a)	(a)	(a)	(a)
Kern River Valley	67	(a)	(a)	(a)	(a)
Walker Basin Creek Valley	16	(a)	(a)	(a)	(a)
Cummings Valley	14	(a)	(a)	(a)	(a)
Tehachapi Valley West	28	(a)	(a)	(a)	(a)
Castaic Lake Valley	2	(a)	(a)	(a)	(a)

(a) Not Determined.

Table 6 Principal ground-water basins in the Sacramento Basin (83)

Basin name	Area of Valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (°F)	Range of dissolved solids (ppm)
Goose Lake Valley	75	1,000,000	(a)	58-69	(a)
South Fork Pit River Valley	93	7,500,000	(a)	72	(a)
Jess Valley	9	(a)	(a)	(a)	(a)
Big Valley	103	3,750,000	(a)	58	1,380
Fall River Valley	100	1,000,000	(a)	56-64	132
Redding Basin	513	(a)	(a)	63-78	1,770
Lake Almanor Valley	7	45,000	(a)	(a)	74-143
Mountain Meadows Valley	10	(a)	(a)	(a)	(a)
Indian Valley	20	100,000	(a)	(a)	71-294
American Valley	7	50,000	(a)	(a)	36-212
Mohawk Valley	8	90,000	(a)	(a)	123-264
Sierra Valley	137	7,500,000	(a)	(a)	118-1390
Upper Lake Valley	15	10,000	5,000	(a)	76-407
Scott Valley	4	5,000	4,500	(a)	(a)
Kalseyville Valley	31	105,000	60,000	(a)	165-617
High Valley	3	9,000	900	(a)	161-650
Burns Valley	2	4,000	1,400	(a)	126-397
Coyote Valley	6	27,000	7,000	(a)	109-239
Collayomi Valley	7	29,000	7,000	(a)	-342
Sacramento Valley	5,000	33,570,000	22,000,000	60-78	99-2790

(a) Not Determined.

Safe ground-water yield for the entire Sacramento Basin is estimated to be 1.6 million acre-feet per year; an annual overdraft estimated to be 100,000 acre-feet exists (5).

North Lahontan Basin

Most usable ground water in the predominantly mountainous North Lahontan Basin occurs in scattered valleys filled with alluvium and material of volcanic origin. The intervening mountainous areas are underlain by igneous rocks of Mesozoic and Cenozoic age. Those rocks contain only small quantities of recoverable ground water and, therefore, are not considered a major source of ground water.

In the North Lahontan Basin, eight valley-fill areas have been identified as significant sources of ground water. The total area of the eight valleys is about 1,300 square miles. The water-bearing deposits range in thickness from about 250 to 1,000 feet. Depending on local conditions, recharge infiltrates at rates of less than 1-1/2 feet per day to more than 10 feet per day in the upper part of alluvial fans and in stream channels. The maximum measured depth to water in the water-bearing deposits is 192 feet. In several valleys there are flowing wells.

Total storage capacity of the seven basins for which determinations have been made is nearly 23,000,000 acre-feet as given in Table 7. The usable storage capacity has not been determined, but the limiting factor is poor water quality (84). Ground-water temperature generally ranges from 50° to 80°F, but has been observed locally as high as 182°F.

Safe ground water yield for the entire North Lahontan Basin is estimated to be 60,000 acre-feet. There is no overdraft (5).

South Lahontan Basin

Most usable ground water in the predominantly mountainous South Lahontan Basin occurs in scattered alluvium-filled valleys. The alluvium consists generally of lenticular beds of unconsolidated to semiconsolidated clay, silt, sand, and gravel of cenozoic age. The intervening mountainous areas are underlain by consolidated sedimentary, igneous, and metamorphic rocks, mainly of Mesozoic age or older. These rocks contain only small quantities of recoverable ground water and, therefore, are not considered a major source of ground water.

In the South Lahontan Basin, 50 valley-fill areas have been identified as significant sources of ground water. The total area of the 50 valleys is more than 13,000 square miles. The water-bearing deposits range in thickness from 30 to about 2,000 feet. Depending on local conditions, recharge infiltrates at rates of less than 1-1/2 feet per day to more than 10 feet per day in the upper part of alluvial fans

Table 7 Principal ground-water basins in the North Lahontan Basin (84)

Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (°F)	Range of dissolved solids (ppm)
Surprise Valley	350	4,000,000	(a)	48-182	166-2000
Madeline Plains	270	2,000,000	(a)	(a)	(a)
Willow Creek Valley	20	(a)	(a)	(a)	(a)
Honey Lake Valley	490	16,000,000	(a)	55-78	170-1350
Tahoe Valley	21	84,000	(a)	(a)	64-182
Carson Valley	20	100,000	(a)	(a)	66-94
Topaz Valley	36	340,000	(a)	(a)	98-203
Bridgeport Valley	100	280,000	(a)	(a)	74-2030

(a) Not Determined.

and in stream channels. The maximum measured depth to water in the water-bearing deposits is more than 975 feet. In several valleys there are flowing wells.

Total storage capacity of the 50 basins as shown in Table 8 is more than 134,000,000 acre-feet. The usable storage capacity has been determined only for Indian Wells Valley where it amounts to 720,000 acre-feet (85). Ground-water temperature generally ranges from 50° to 80°F, but has been observed locally as high as 137°F.

Safe ground-water yield for the entire South Lahontan Basin is estimated to be 300,000 acre-feet per year; an annual overdraft also estimated to be 300,000 acre-feet exists (5).

Colorado Desert Basin

Most usable ground water in the Colorado Desert Basin occurs in alluvium-filled valleys which occupy about half the basin. The alluvium consists generally of lenticular beds of unconsolidated clay, silt, sand, and gravel of Cenozoic age. The intervening mountainous areas are underlain by consolidated sedimentary, igneous, and metamorphic rocks, mainly of Mesozoic age or older. These rocks contain only small quantities of recoverable ground water and, therefore, are not considered a major source of ground water.

In the Colorado Desert Basin, 45 valley-fill areas have been identified as significant sources of ground water. The total area of the 45 valleys is about 12,800 square miles. The water-bearing deposits range in thickness from about 48 to 2,800 feet. Depending on local conditions, recharge infiltrates at rates of less than 1-1/2 feet per day to more than 10 feet per day in the upper part of alluvial fans and in stream channels. The maximum measured depth to water in the water-bearing deposits is 644 feet. In several valleys there are flowing wells.

Water in storage (in 1965) in the 45 valleys totaled 158,000,000 acre-feet and is given in more detail in Table 9. The usable storage capacity has been determined only for Coachella Valley, where it amounts to 3,600,000 acre-feet. Ground-water temperature generally ranges from 60° to 90°F, but temperatures of more than 500°F have been observed locally (36). The dissolved-solids content of the water varies greatly, depending on local conditions. Prior to importation of Colorado River water, most water used in the Coachella Valley came from ground water (87, 88).

Safe ground-water yield for the entire Colorado Desert Basin is estimated to be 100,000 acre-feet per year; an annual overdraft estimated to be 200,000 acre-feet exists (5).

Table 8 Principal ground-water basins in the South Lahontan Basin (85)

Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (^{o}F)	Range of dissolved solids (ppm)
Mono Valley	246	3,400,000	(a)	(a)	60-2060
Adobe Lake Valley	62	320,000	(a)	(a)	135-284
Long Valley	119	160,000	(a)	(a)	?-1500
Owens Valley	1,031	12,000,000	(a)	(a)	100-400
Black Springs Valley	46	230,000	(a)	(a)	(a)
Fish Lake Valley	68	320,000	(a)	(a)	220-365
Deep Springs Valley	41	740,000	(a)	(a)	?-200,000
Eureka Valley	156	2,070,000	(a)	(a)	(a)
Saline Valley	211	2,430,000	(a)	(a)	?-3760
Death Valley	1,316	11,200,000	(a)	69-104	300-10250
Wingate Valley	66	870,000	(a)	(a)	(a)
Middle Amargosa Basin	615	6,800,000	(a)	(a)	490-2300
Lower Kingston Valley	293	3,390,000	(a)	(a)	5385-8540
Upper Kingston Valley	271	2,130,000	(a)	70-?	344-1080
Riggs Valley	100	1,190,000	(a)	(a)	(a)
Red Pass Valley	155	870,000	(a)	(a)	(a)
Bicycle Valley	122	1,710,000	(a)	76-?	608-?
Avawatz Valley	67	580,000	(a)	(a)	(a)
Leach Valley	68	650,000	(a)	(a)	(a)
Pahrump Valley	400	690,000	(a)	70-?	176-841
Mesquite Valley	125	580,000	(a)	66-70	300-5462
Ivanpah Valley	303	3,090,000	(a)	68-?	231-2228
Kelso Valley	370	5,350,000	(a)	(a)	272-570
Broadwell Valley	120	1,220,000	(a)	73-?	470-1260
Soda Lake Valley	590	9,300,000	(a)	56-83	242-3350
Silver Lake Valley	40	380,000	(a)	(a)	1100-1740

Table 8 con't. Principal ground-water basins in the South Lahontan Basin (85)

Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (^{o}F)	Range of dissolved solids (ppm)
Cronise Valley	154	1,000,000	(a)	73-?	455-3130
Langford Valley	48	760,000	(a)	74-?	472-634
Coyote Lake Valley	146	1,470,000	(a)	68-106	312-2480
Caves Canyon Valley	100	1,150,000	(a)	65-71	198-1270
Troy Valley	133	2,170,000	(a)	68-72	278-3310
Lower Mojave River Valley	307	5,100,000	(a)	55-77	190-2340
Middle Mojave River Valley	427	5,420,000	(a)	55-77	145-3900
Upper Mojave River Valley	600	8,540,000	(a)	60-74	85-2760
El Mirage Valley	120	1,760,000	(a)	(a)	320-14100
Antelope Valley	1615	5,400,000	(a)	50-79	123-7700
Tehachapi Valley East	22	138,000	(a)	(a)	338-567
Fremont Valley	331	4,800,000	(a)	66-82	349-28000
Harper Valley	514	6,460,000	(a)	64-77	316-14700
Goldstone Valley	27	210,000	(a)	(a)	?-1818
Superior Valley	172	1,750,000	(a)	(a)	284-2260
Cuddleback Valley	130	1,380,000	(a)	70-72	375-4734
Pilot Knob Valley	204	2,460,000	(a)	48-60	389-1510
Searles Valley	251	2,140,000	(a)	61-137	11900-420000
Salt Wells Valley	34	320,000	(a)	(a)	?-22700
Indian Wells Valley	519	5,120,000	720,000	63-93	141-232000
Coso Valley	52	390,000	(a)	(a)	(a)
Rose Valley	61	820,000	(a)	(a)	350-1300
Darwin Valley	70	400,000	(a)	(a)	155-750
Panamint Valley	365	3,400,000	(a)	62-74	282-272000

(a) Not Determined.

Table 9 Principal ground-water basins in the Colorado Desert Basin (86)

Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (°F)	Range of dissolved solids (ppm)
Lanfair Valley	275	3,000,000	(a)	(a)	230-2,000
Fenner Valley	720	5,600,000	(a)	(a)	287-872
Ward Valley	774	8,700,000	(a)	(a)	394-21,600
Rice Valley	297	2,280,000	(a)	(a)	661-2,690
Chuckwalla Valley	872	9,100,000	(a)	70-114	274-12,300
Pinto Basin	306	230,000	(a)	70-84	123-827
Cadiz Valley	428	4,300,000	(a)	(a)	615-several thousand
Bristol Valley	710	7,000,000	(a)	(a)	289-298,000
Dale Valley	262	2,000,000	(a)	76-146	1,070-304,000
Twentynine Palms-Deadman Valley Area	660	4,900,000	(a)	52-115	86-1,180
Lavic Valley	36	270,000	(a)	(a)	?-1,679
Means-Lucerne Valley Area	570	4,600,000	(a)	60-77	131-5,510
Morongo Valley	14	100,000	(a)	60-72	212-658
Coachella Valley	692	39,000,000	3,600,000	70-208	147-3,180
West Salton Sea Valley	286	(a)	(a)	?-136	2,260-10,400
Coyote Creek-San Felipe Valley Area	500	6,800,000	(a)	62-97	300-2,152
Coyote Wells Valley	103	1,700,000	(a)	(a)	442-8,660
Imperial Valley	1,869	14,700,000	(a)	70-500	694-3,560
Orocopia Valley	139	1,500,000	(a)	(a)	460-1,498
Chocolate Valley	120	1,000,000	(a)	75-174	356-16,348
East Salton Sea Valley	453	360,000	(a)	71-75	356-3,850
Amos-Ogilby Valley	441	5,800,000	(a)	70-?	370-1,600
Yuma Valley	168	4,600,000	(a)	(a)	935-14,680

Table 9 con't. Principal ground-water basins in the Colorado Desert Basin (86)

Basin name	Area of valley floor (sq mi)	Total storage capacity (acre-feet)	Usable storage capacity (acre-feet)	Range of temperature (^{o}F)	Range of dissolved solids (ppm)
Arroyo Seco Valley	427	7,000,000	(a)	72-84	330-1,692
Palo Verde Valley and Mesa	476	11,800,000	(a)	70-?	356-11,000
Quien Sabe Point Valley	39	230,000	(a)	(a)	(a)
Calzona-Vidal Valley	314	3,100,000	(a)	73-90	450-1,060
Chemehuevis Valley	440	4,700,000	(a)	70-?	351-1,094
Needles Valley	136	1,100,000	(a)	(a)	831-1,600
Piute Valley	273	2,400,000	(a)	(a)	(a)

(a) Not Determined.

NEVADA

Nevada, with an area of approximately 70.7 million acres is the seventh largest state. The average precipitation is less than any other state and most of that occurs during the winter months. Only about 6% of the land is under cultivation and the high altitude results in a wide daily variation of temperatures.

In 1950, the water use in the state amounted to 1,600,000 acre-feet of which 190,000 were from the ground-water. By 1956 the total water use had risen to 2,300,000 acre-feet of which 530,000 acre-feet came from the ground-water supply. The total average precipitation in the state is 50 million acre-feet of which about 8% or 4 million acre-feet is the average annual runoff. About half the runoff or 2 million acre-feet end up recharging the ground-water reservoirs of the state. By 1962 there were 5 valleys which were overdrawing their annual supply and several others were using practically all of their annual supply.

As the demand for water becomes more acute, the ground-water basins of the state will be required to supply more and more of the state's water needs. This is already evidenced by the increase from 190,000 acre-feet per year in 1950 to 530,000 acre-feet per year in 1965. This represents an increase of about 180% in fifteen years, or 12% increase per year based on the 1950 figure.

There are a number of problems associated with developing the ground-water in Nevada. The problems may be classified in a general way as follows: (1) Natural supply and distribution. (2) Natural losses. (3) Conservation and management. (4) Water quality, and (5) Legal.

The natural ground-water yield approaches about 2 million acre-feet. In addition to the perennial yield there are 200 million acre-feet in storage in the upper 100 feet of the saturation zone. One of the problems in developing the stored ground-water, is the problem of determining how far it is feasible to lower the ground-water table. In some areas, the lowering of the ground-water would help control the loss of water through phreatophytes. If the ground-water table is lowered excessively, the pumping costs will rise thus increasing the cost of water. Most of the water-bearing formations consist of fine water-bearing materials and it is difficult to develop a well which will produce large quantities of flow. The Sierra front and the Humboldt River Basin have the best water supplies, while the southern part of the state is very arid and already short of water in certain areas.

There are approximately 3 million acres of phreatophytes in Nevada which waste approximately 1-1/2 million acre-feet of water. This is a substantial portion of the potential ground-water left to be developed in the state. In order to put this wasted water to beneficial use, methods will have to be found to salvage this water which is now being lost to evapotranspiration. Eradication of phreatophytes also poses the potential problem of increased erosion in some areas.

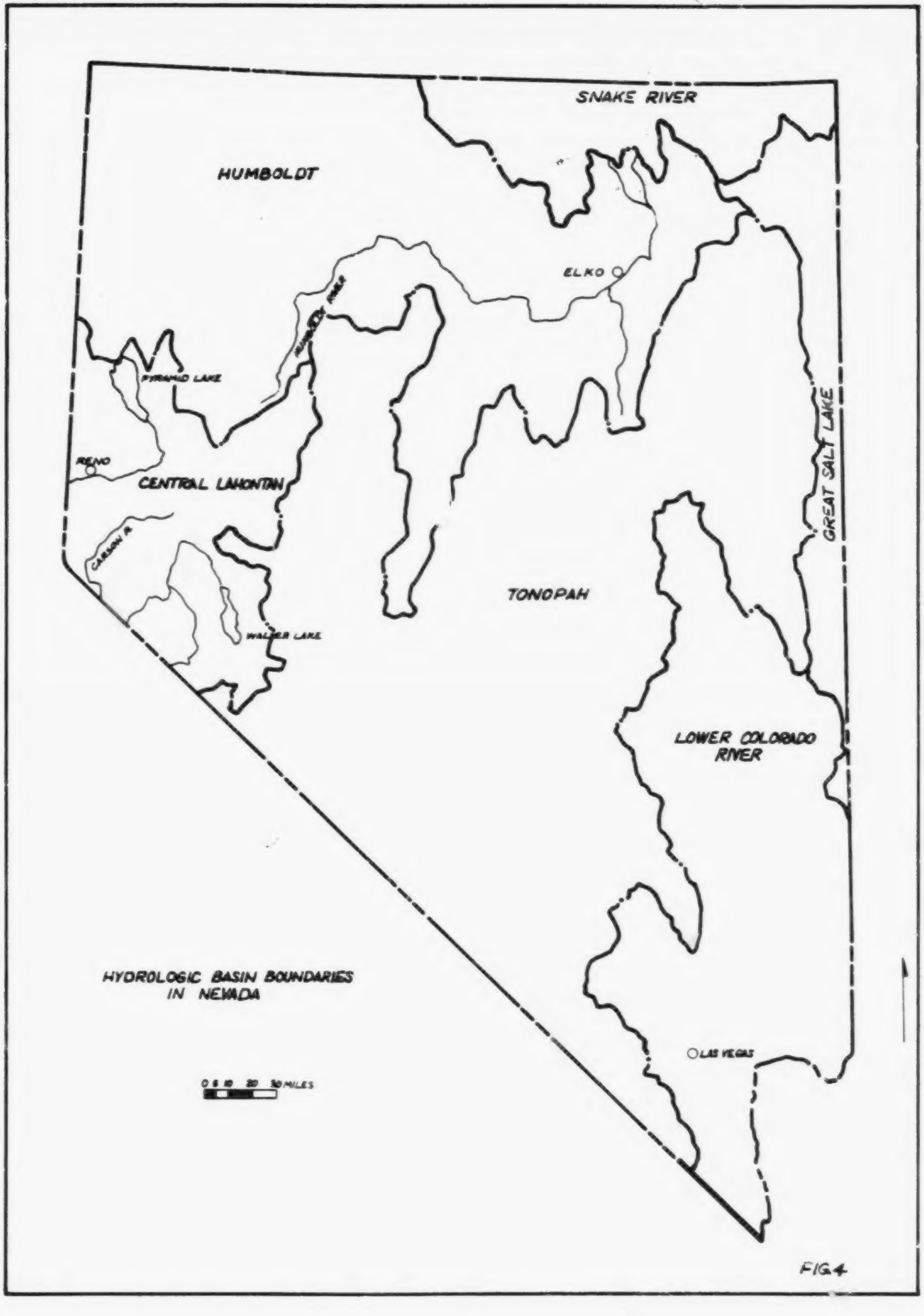
Many of the ground-water basins lie below closed basins with internal drainage. The resulting accumulation of salts over large areas has contributed to the mineralization of the ground-water underlying some two million acres in the state. As a result of this mineralization, development of ground-water may be severely restricted in many valleys of the state.

The legal problems connected with ground-water development are numerous and will continue to increase. The infringement of water rights is already a problem in many areas. As the demand for water approaches or exceeds the natural supply, the problem of preferential use among domestic, municipal, irrigation, and other uses will arise. Since some ground-water basins are interconnected geologically and there is flow between basins, there will be problems of water rights and water management that will have to be solved. There are also a number of ground-water basins which cross state boundaries, so as use of water along boundaries increase, this problem will have to be resolved.

Nevada has been divided into 253 hydrographic areas which are essentially valleys. Each valley is partly filled with alluvium which is the principal storage reservoir for ground-water. These valleys have become the basic social, economic and water development units in Nevada. Most boundary lines of hydrographic ridges have been interpreted from the most detailed topographic maps available in 1967. The size of the hydrographic areas range from 9 square miles to 2,182 square miles and the valley floor elevations range from 800 feet above MSL to 7,200 feet above mean sea level. There are 82 small hydrographic areas (1-200 square miles), 151 median sized areas (201-1,000 square miles) and 20 large areas (1,001-2,200 square miles). These hydrographic areas are grouped into 14 hydrographic areas. The large scale unifying hydrographic features which were the general basis for the areas fall into three broad categories: (1) drainage basins of large regional streams, (2) drainage basins that have no large regional streams, and (3) groups of mostly topographically closed valleys. The areas vary in size from 106 square miles to 46,783 square miles. The above areas have been combined into six hydrologic basins as shown on Figure 4.

Humboldt Basin

The average annual precipitation for this basin is 10 inches with an estimated average runoff of 850,000 acre-feet. Most of the valleys in this basin are underlain by alluvial deposits which act as underground reservoirs, that are recharged by water seeping down from the surface. The natural recharge in this region is estimated at 480,000 acre-feet. Based on the 1965 use level, there is still about 390,000


SNAKE RIVER
HUMBOLDT
ELKO
HUMBOLDT RIVER
PYRAMID LAKE
RENO
CENTRAL LAHONTAN
CARSON R.
WALKER LAKE
TONOPAH
GREAT SALT LAKE
LOWER COLORADO RIVER
LAS VEGAS
0 5 10 20 30 MILES

HYDROLOGIC BASIN BOUNDARIES IN NEVADA

FIG.4

acre feet of ground water which could be developed annually. In addition to the natural ground water supply, water could be mined from the upper 100 feet of the ground water reservoir. It is estimated that over a 50 year period, this basin could produce an annual ground-water supply of 870,000 acre feet from the upper 100 feet of the storage reservoir. These figures indicate that there are over 1,000,000 acre feet of water annually available for future development.

Central Lahontan Basin

The Central Lahontan Basin might be considered an arid region with an average precipitation of only 8.4 inches. The average annual runoff of 110,000 acre feet is lower than any other area in Nevada. The average annual recharge to the ground water of 104,000 acre feet is about the same as the surface runoff. As of 1965 about half of the annual yield was already being used and so the potential of a stable ground water supply is not very large. The upper 100 feet of the ground water reservoir could be depleted at an average rate of about 320,000 acre feet per year for a 50 year period, but this would have to be temporary and the annual cost of extraction would slowly rise as a result of the falling water table.

Tonopah Basin

The average precipitation in this basin is about 9.5 inches per year. The estimated runoff is on 290,000 acre feet and the annual average recharge to the ground water is 680,000 acre feet. The annual use in 1965 was about 200,000 acre feet from the ground water leaving a future development potential of about 480,000 acre feet. Using an arbitrary 50 year period, the one-time ground-water storage could be depleted at an annual rate of 1,000,000 acre feet. This means that an additional ground-water supply of about 1,500,000 acre-feet could be developed in this basin.

Lower Colorado River Basin

In 1965, the ground-water pumpage in this part of Nevada was about 115,000 acre feet. However, the water is being pumped at a rate in excess of the replenishment rate so that the water table is falling. It is estimated that the ground water storage to a depth of 1200 feet is 190 million acre feet so that the storage reserve is fairly large. The water supply development in this area is from the ground water and until there are new sources of water found, it seems that the one-time ground water storage reservoir will continue to be the main source of water in this area.

Great Salt Lake and Snake River Basins

Both of these basins are small and are low population regions so that the ground water supply in these two areas is not considered to be very important at the present time, within the state of Nevada.

UTAH

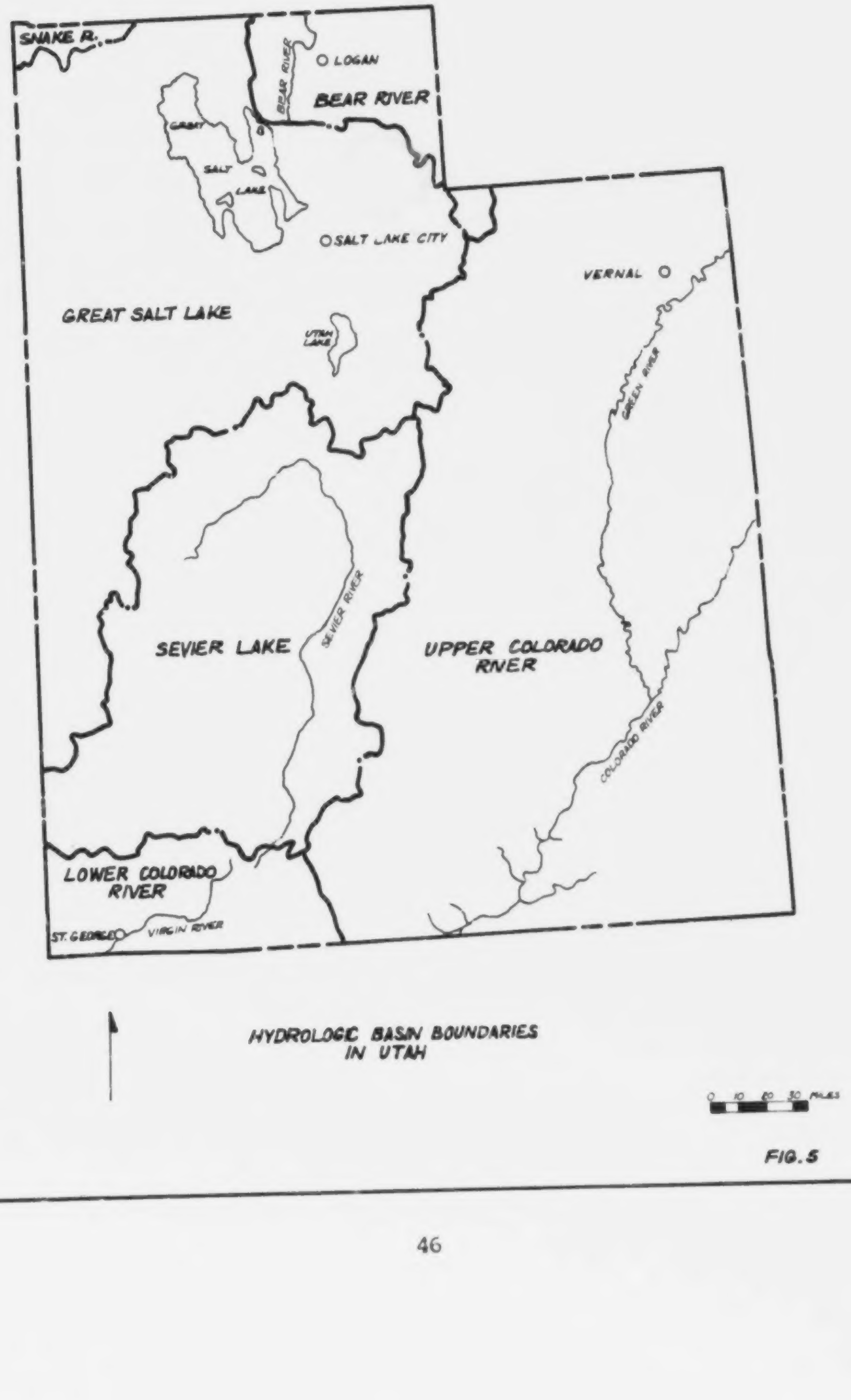
Utah has an area of 84,916 square miles and an average precipitation of 11.5 inches. The precipitation varies from 5 inches or less in the driest parts of the Great Basin to over 60 inches on some of the highest peaks of the Wasatch Mountains. The average annual runoff is 0.25 inches or less in the driest parts to about 20 inches or more in the highest mountains. Irrigation is the major water user in the state and Table 10 shows the various uses of water in the year 1960.

Table 10 Water Use in Utah in 1960

	Surface Water		Ground Water		Total	
Use	Acre-feet per year	Mgd	Acre-feet per year	Mgd	Acre-feet per year	Mgd
Public	130,000	120	110,000	100	240,000	220
Rural	9,700	8.7	12,000	11	22,000	20
Industrial:						
Total	250,000	230	65,000	58	320,000	290
Public-utility fuel-electric power	86,000	77	--	--	86,000	77
Irrigation	3,400,000	3,000	350,000	310	3,800,000	3,300
TOTAL	3,800,000	3,400	540,000	480	4,300,000	3,900

Of the 1,165,000 irrigated acres of land in 1960, less than half had an adequate water supply. However, since the average annual runoff is 8.2 million acre feet per year (15), there is still room for development in Utah. In addition to the surface water supply, there are still many areas where the ground water has not been fully developed so Utah has a reasonable growth potential as far as her available ground water supply is concerned. This potential is reflected by the fact that in 1970 the use of ground water rose to a total of 680,000 acre feet from a total of 481 producing wells (89). This represents an increase.

The hydrologic basin boundaries are shown on Figure 5. About half the state (the western part), lies in the Great Basin which is a closed basin and is generally arid or semiarid as far as precipitation is concerned. The eastern half of the state lies principally in the Colorado River drainage basin. The Wasatch Range and the High Plateaus of Utah form a belt of high land running down through the state basically separating the Great Basin and the Colorado River Basin. A very


SNAKE R.
BEAR RIVER
LOGAN
BEAR RIVER
GREAT SALT LAKE
SALT LAKE CITY
VERNAL
GREAT SALT LAKE
UTAH LAKE
GREEN RIVER
SEVIER RIVER
SEVIER LAKE
UPPER COLORADO RIVER
COLORADO RIVER
LOWER COLORADO RIVER
ST. GEORGE
VIRGIN RIVER
0 10 20 30 MILES

HYDROLOGIC BASIN BOUNDARIES IN UTAH

FIG. 5

small area in the northwest corner of the state drains into the Snake River Basin.

The principal supplies of ground water are found in the alluvial fill of the valleys of the Great Basin and in alluvium along a few streams in the Colorado Plateaus. Ground water is also found in the sedimentary strata of the bedrock on the flanks of the Uinta Mountains in the southeastern part of the Colorado Plateaus and in scattered areas throughout the state.

Small quantities of ground water can be obtained from wells throughout much of Utah, but large supplies that are of suitable chemical quality for irrigation, public supply or industrial use, generally can be obtained only in specific areas. Only a few wells outside of these areas yield large supplies of water of good chemical quality.

Less than 2 percent of the wells in Utah obtain water from consolidated rocks. The consolidated rocks that yield the most water are lava flows such as basalt, which contains openings enlarged by solution; and sandstone, which contains interconnected openings between the grains that form the rock. Most of the wells that tap consolidated rocks are in the eastern and southern parts of the state, in areas where water supplies cannot be readily obtained from unconsolidated rocks.

More than 98 percent of the wells in Utah draw water from unconsolidated rocks. These rocks may consist of boulders, gravel, sand, silt, or clay, or a mixture of some or all of these sizes. Wells obtain the largest yields from the coarser materials that are sorted into deposits of equal grain size. Most wells that tap unconsolidated rocks are in large intermountain basins, which have been partly filled with debris from the adjacent mountains.

Upper Colorado River Basin

The rocks of the Upper Colorado Basin which is located in Utah consist of eight major geologic groups (11) based on general hydrologic properties. Most of the Colorado Plateau is made up of outcrops of shale, siltstone, fine grained sandstone, igneous and metamorphic rocks and these formations do not make good aquifers which produce large capacity wells. Only about 4% of the area is covered with exposed deposits of unconsolidated materials and volcanic rock. It is this relatively small area which has the potential of producing good wells. The ground water storage in the upper 100 feet of aquifer is estimated at about 45 million acre feet with only 7 million acre feet in the area of high permeability. No good estimate is available on the potential perennial yield of the Utah part of the Upper Colorado River Basin.

About 40 to 45 thousand acre feet of water are withdrawn from the ground water each year in this area. The principle uses are for irrigation, public supplies, domestic and stock use, and industrial use.

Great Basin

This basin covers most of the western section of the state of Utah. Most of this basin is covered with unconsolidated deposits of alluvial fill which is often very thick and highly porous. The rest of the area consists of various types of consolidated rocks which generally have a low porosity.

No estimates are available for the perennial yield of this area but some work has been done on evaluating the water in storage in the Great Basin. In the upper 100 feet of the ground-water reservoirs in the Utah part of the Great Basin, there is 71,900,000 acre feet of water stored (7). For development purposes, this would permit mining the water at an annual rate of 1.4 million acre feet per year for 50 years.

The 1965 ground water withdrawal in the Great Basin of Utah was about 600,000 acre feet. The yield of an average well was about 1,000 g.p.m., although the flows varied from 10 to 8,600 g.p.m. Large capacity pumped wells account for the major part of the withdrawals. It seems that there is a great potential for the development of ground water in Utan, especially in the Great Salt Lake area of the Great Basin.

Lower Colorado River Basin

Only a small part of the Lower Colorado River Basin is in Utah and that is the Virgin River drainage basin. Only small amounts of ground water are used in this area and the amount available for future development is extremely limited. The ground water table is deeper than 500 feet in about 80% of the area and only about 5% in the valley of the Virgin River is less than 200 feet from the surface of the ground.

Snake River Basin

Only a very small area in Utah lies in the Snake River Basin. Little or no data are available for this area, but the area is so small that it is believed that there are no significant ground-water supplies or pollution problems in this area.

SECTION V

GROUND WATER POLLUTION INDICATORS

Ground water is one of the most widely distributed resources of man and one of the most important. It is subject to natural and man-made pollution and since it is so valuable to man's existence, everything possible should be done to preserve this resource. In order to evaluate the ground water pollution problem, one must have some understanding of the indicators which reflect a condition of pollution. In addition to a knowledge of the indicators, it is necessary to understand something about the critical concentrations of a given indicator which will begin to make the water unfit for certain beneficial uses. It is also important to know something about the processes which result in the pollution of the ground water by the various indicators.

Ground water pollution is generally determined by the presence of some or many of the following indicators:

1. Chemical indicators - Total dissolved solids, chlorides, sulphates, calcium, manganese, fluorides, sodium, iron, boron, nitrates, phosphates, and others.

2. Biological indicators - Coliform organisms, biochemical oxygen demand, viruses, bacteria, and etc.

3. Industrial indicators - pesticides, herbicides, acids, arsenic, heavy metals, detergents, phenols, gasoline, and many others.

The above list is only a partial one but it does domonstrate the extensiveness and the complexity of the ground-water pollution problem. It should also be pointed out here that many of the pollution indicators are principally a result of man's living habits and his activities, while many of the same indicators get into the ground water through natural processes not affected much by man and his activities.

A pollutant may be undesirable because of it's toxicity--such as arsenic for humans and animals, boron for agricultural crops--or because of a specific undesirable characteristic related to a specific use--such as "hardness" in boiler waters or the laundry industry. It may be undesirable because of a specific pollutant, as mentioned above, or because of the combined effect of a number of pollutants, such as the effect of total dissolved solids in agricultural and other uses. A pollutant may be objectionable in relation to one specific use yet not for others. Undetected pollutants may be present in any water, since waters are usually monitored and tested only for known or suspected pollutants.

In the region under study much of the area is arid or semiarid and the soils are relatively high in many minerals, especially the chlorides, sulphates and carbonates of potassium, calcium, magnesium, and sodium. The soils are neutral or alkaline in reaction. During the weathering process large amounts of soluble salts may result from the parent rocks. Arid climates involve both low rainfall and humidity. When the rainfall does come, evaporation is rapid and there is little leaching of the soil. As a result, the arid soils remain richer in many of the mineral constituents than do soils in humid regions where leaching is a regular process (15).

Arid soils are also characterized by an accumulation of calcium carbonate at some point in the soil profile. This zone of accumulation of calcium carbonate is closely related to rainfall, both total amount and seasonal distribution. At some locations, the calcium carbonate accumulations become solidified causing hard layers which may limit root penetration and impede drainage. Salt accumulation is more severe in the lower-lying areas of drainage basins because more water is generally evaporated from the lower areas. The higher concentrations of salts in the arid soils tend to increase the potential of the mineral pollution of the ground water which lies below.

The process of mineral accumulation in the soil is known as mineralization. It is usually associated with restricted drainage.

Sodium salts generally predominate in the early stages of mineralization. Calcium carbonate and calcium sulfate are less soluble so they accumulate more slowly. Alkalization takes place when the sodium ions replace the cations previously adsorbed on the soil particles. As the percentage of exchangeable sodium is increased, the soil becomes more alkaline in reaction. Salinization deals mainly with the total dissolved salts while alkalinization principally involves the amount of exchangeable sodium present.

In the western states there are many areas where salts have accumulated in the soils so that large areas have become saline or alkaline in nature. When excessive rains or irrigation applications cause water to flow down through those soils to the ground water basin below, some of these high concentrations of salts are leached out and carried into the ground water reservoir. Table 11 lists the extent of this type of problem in eighteen states, and the four states included in the study of this report are underlined.

Various standards of water quality are used depending upon the use of the water. Standards for irrigation, domestic and a number of industrial uses have been formulated by various agencies (90, 91). Details of some of the standards applicable to various uses are presented in the Appendix of this report.

Table 11 Saline or alkaline areas in eighteen western states 1960 (90)

State	Total Irrigable acreage	Salt-free		Saline or alkaline	
		Acres	%	Acres	%
Arizona	1,565,000	1,166,170	74.5	398,830	25.5
California	11,500,000	7,755,049	67.4	3,744,951	32.6
Colorado	2,911.532	1,829,704	65.1	981,828	34.9
Hawaii	117,418	71,863	61.2	45,550	38.8
Idaho	1,880,063	1,627,118	86.5	252,945	13.5
Kansas	421,545	319,215	75.7	102,330	24.3
Montana	1,242,728	1,045,057	84.1	197,671	15.9
Nebraska	1,218,385	928,385	76.2	290,000	23.8
Nevada	1,121,916	646,316	57.6	475,600	42.4
New Mexico	850,000	659,000	77.5	191,000	22.5
North Dakota	2,636,500	1,819,870	69.0	816,630	31.0
Oklahoma	826,650	632,900	76.6	193,750	23.4
Oregon	1,490,394	1,387,033	93.1	103,361	6.9
South Dakota	1,697,974	501,708	29.5	1,196,266	70.5
Texas	2,198,950	1,923,096	87.5	275,854	12.5
Utah	1,390,222	877,440	61.1	512,782	36.9
Washington	2,221,484	1,955,230	88.0	266,254	12.0
Wyoming	1,261,132	981,429	77.8	279,703	22.2
TOTAL	36,451,893	26,126,588	71.6	10,325,305	28.4

The information presented in the paragraphs which follow represents a summary of measured pollution indicators for which data are available to us. It's presentation here does not imply any level of statistical significance nor any degree of adequacy of the data in a quantitative sense. Rather, it is intended to give a general indication of the pollutants which have been detected and measured within the study area.

Arizona

There are many measured indications of ground water pollution throughout the entire state of Arizona. The most common of the measured indicators, (mineralization of the ground water) is found in all of the waters of the state. The type of mineral, the amount, and the time distribution vary considerably. There is often considerable variation in the amount of mineralization in waters from different depths. Distribution of high concentrations of total dissolved solids in the ground waters of Arizona is shown in Figure 6. This figure indicates that there are a number of areas in Arizona where the mineralization os the ground water exceeds 1000 mg/l.

Hardness of water is a problem in many areas in Arizona. Fluorides in excessive amounts are also found in many Arizona ground waters. Excessive hardness and fluorides become a problem when the water is to be used for drinking water.

A discussion of measured indicators of pollution in each of the hydrologic basins of Arizona is presented in the paragraphs below.

CENTRAL GILA RIVER AND ADJOINING MEXICAN DRAINAGE

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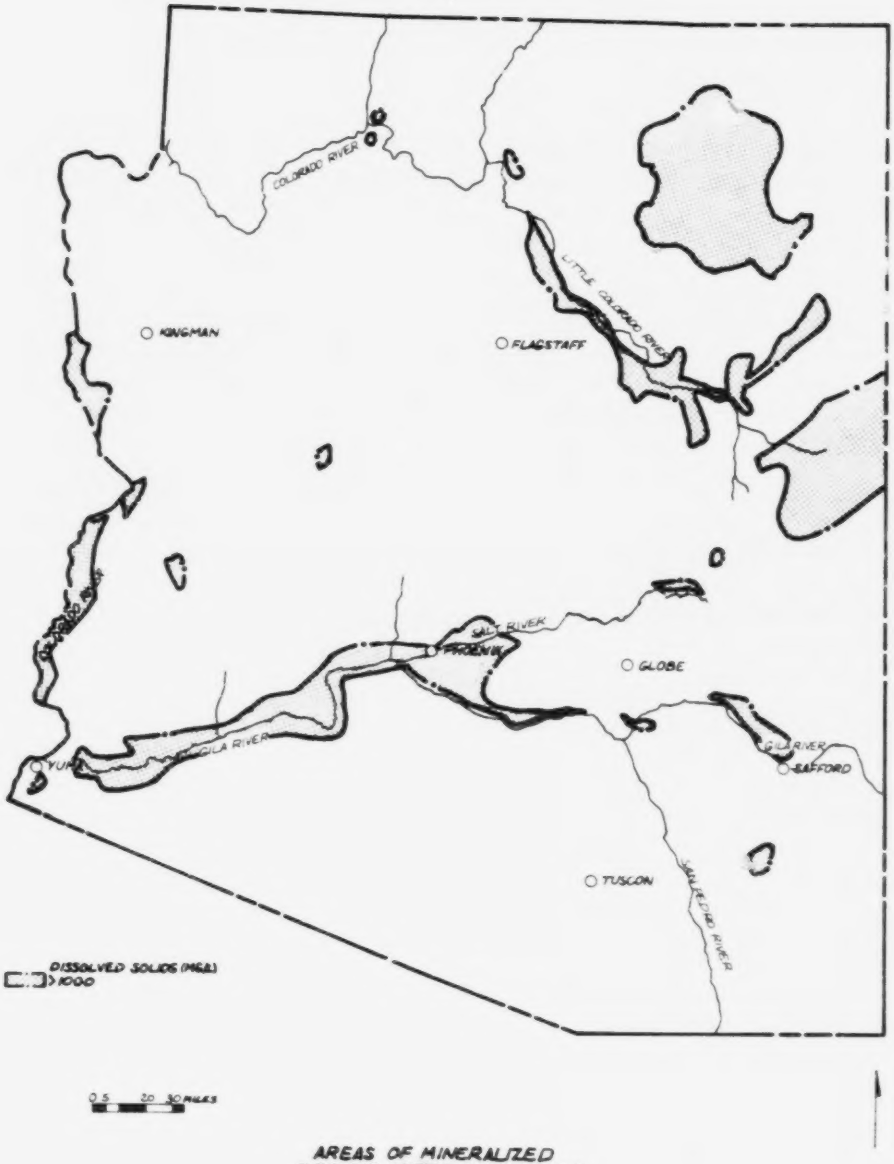
Mineralization

The ground waters of this basin are among the most heavily used in the whole project area. The Salt River Valley is one of the major hydrologic units in this basin and its name is the result of the character of the water and soil. Most of the ground water basins in this drainage area are over-developed and yield water which is highly mineralized (17, 19, 22, 21). Serious problems were recognized more than twenty years ago by McDonald (20). Measurements of total dissolved soilds show many wells yielding water in excess of 3000 p.p.m. The salt content of ground waters is generally quite variable; with wells at the center of heavy water using areas often showing highest concentrations of salts, and those near the outer edge maintaining good quality. Range of total dissolved solids varies from about 200 (not many wells are this low in TDS) to above 7000 p.p.m., and are very commonly between about 700 and 2000 p.p.m. The deeper aquifers usually yield water of higher quality than the shallow ones. Ground water levels are declining and the concentration of total dissolved solids is generally increasing throughout the basin. At many locations, the sodium content of the water is high.


COLORADO RIVER
LITTLE COLORADO RIVER
KINGMAN
FLAGSTAFF
COLORADO RIVER
SALT RIVER
PHOENIX
GLOBE
GILA RIVER
YUMA
GILA RIVER
SAFFORD
TUSCON
SAN PEDRO RIVER
DISSOLVED SOLIDS (MG/L)
>1000
0 5 20 30 MILES

AREAS OF MINERALIZED GROUND WATER IN ARIZONA

FIG. 6

Fluoride

This basin has a fluoride problem at many locations throughout the basin. The problem appears to be greatest in the south portions of the basin, with a measurement of 9 p.p.m. being reported on the Papago Indian Reservation by Heindl (93). Concentrations in excess of 1.5 p.p.m. are found at many locations throughout the basin. As indicated by the drinking water standards in Table A-2 these concentrations are very high.

Boron

Boron does not seem to be a great problem in this basin. Concentrations up to about one part per million have been noted in the southern part of the area.

Nitrate

Nitrate concentrations in excess of 100 p.p.m. are common in the Salt River Valley, especially in the Phoenix metropolitan area; and in the Upper Santa Cruz area near Tucson (94, 24, 27, 21).

Heavy Metals

Some indications of heavy metals in the ground water have been noted in the area of Phoenix and Tucson--zinc, chromium, and cadmium--but the problem has apparently been solved.

UPPER GILA RIVER AND ADJOINING MEXICAN DRAINAGE

Mineralization

Mineralization of ground water in this basin is somewhat variable, being high in the San Pedro, Willcox, and Safford sub-basins; and generally not so high in the others, many of which are not over-developed from a ground water point of view.

Fluorides

Fluorides in ground water are above the recommended limit for domestic water in many parts of this basin.

LOWER GILA RIVER BASIN

Mineralization

Ground waters in this basin are very highly mineralized. In the Wellton-Mohawk area, ground waters are pumped for drainage purposes only, and total dissolved solids run as high as 18,000 p.p.m. In the Palomas Plain, concentrations as high as 5000 p.p.m. have been measured.

Most waters have high sodium content.

Fluoride

Fluoride concentrations in excess of the recommended limit are found at many locations.

Boron

Excessive concentrations of boron are found in this basin, especially in the Dateland area.

Lithium

Several samples of water in the Dateland-Hyder area contained excessive lithium, according to Weist (70).

COLORADO RIVER BASIN

Most of the ground water potential in this basin is located along the lower main stem of the river, in the alluvial material. This basin, as arbitrarily designated for this report also includes some lands of the Colorado Plateau in northern Arizona, and considerable desert area which drains into the Colorado River. Because of these wide differences in the area included in this basin, the quality of ground water also varies considerably.

Mineralization

Although there are many wells in the Yuma area which yield good quality water, there are also many which have total dissolved solids content from 1000 to 5000 p.p.m. In the Ranegrass Plain, the waters generally have fairly high total dissolved solids--up to about 4000 p.p.m. In the Big Sandy Valley (95) the waters are generally of good quality, but some of the shallow waters are quite saline. Water in the Kingman area is generally good, with maximum TDS of 750 having been measured.

Fluoride

High concentrations of fluoride have been noted in the Ranegrass Plain and Big Sandy Valley.

LITTLE COLORADO RIVER BASIN

Mineralization

The waters of this basin come mainly from the sandstone between the Mogollon Rim and the Little Colorado River. These waters are of good quality near the Mogollon Rim but increase in salinty as they move toward the river. At some locations the total dissolved solids are as high as 70-0 p.p.m., and the water must be diluted with river water before it can be used for irrigation.

California

There is considerable variation in ground water quality in the state of California. Quality deterioration through the accumulation of salts of various kinds must rank as the most important of all of the pollution factors. Many other indicators of pollution have been noted at various locations throughout the state. Distribution of high concentrations of total dissolved solids in the ground waters of California is shown in Figure 7. A detailed discussion of each of the nine hydrologic basins of the state follows. Data and general information in this portion of the report are taken mainly from reports of the Water Resources Council, the U.S. Geological Survey, and various reports of the California Department of Water Resources (5, 6, 77, 96) and others specifically cited in the following paragraphs.

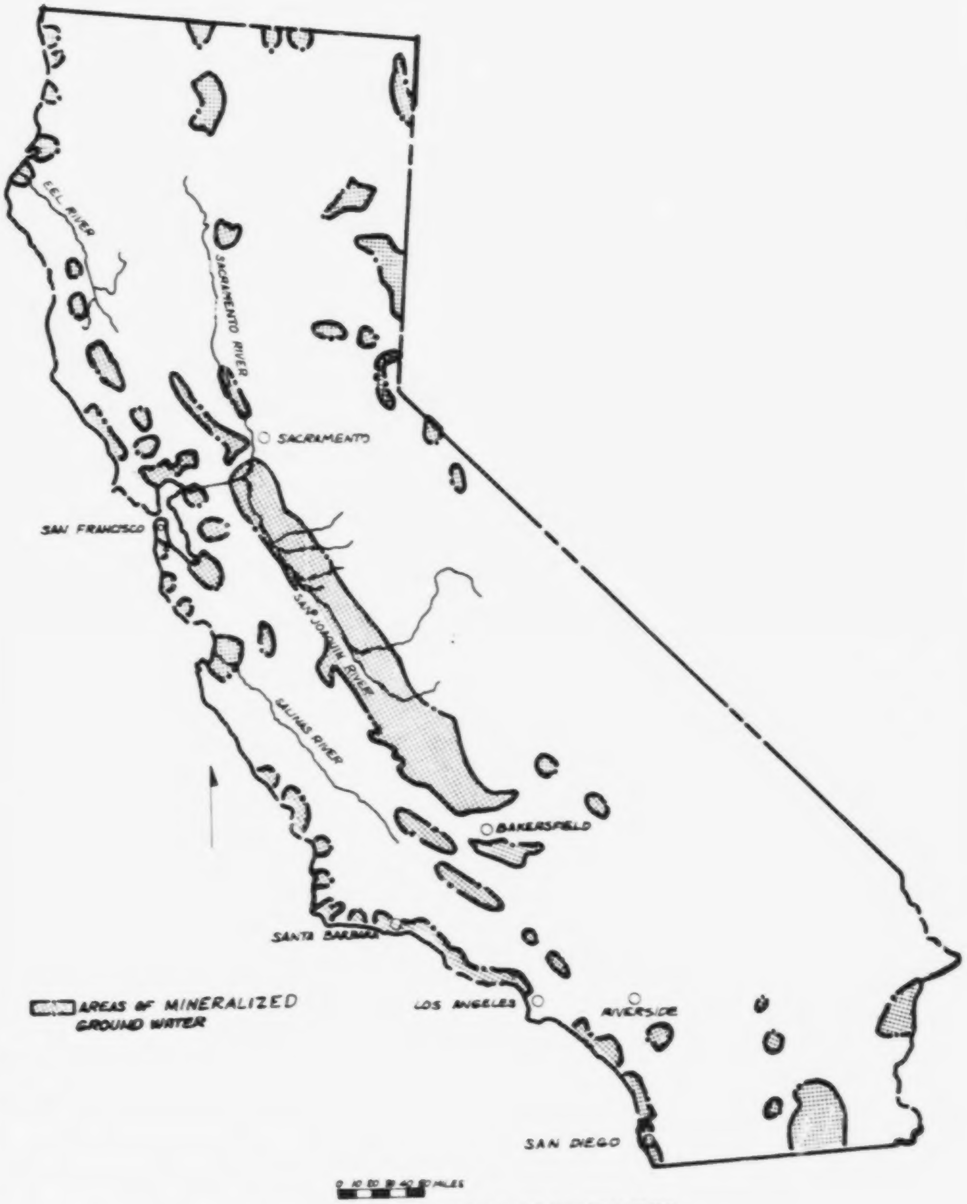
NORTH COASTAL BASIN

This basin is the only portion of the entire area covered by this report which does not have an arid climate. The climatic effects on natural mineral accumulations in the ground water described above are evident here, and the extent of mineralization is limited in most parts of this basin. The basin is sparsely populated, and the man-made pollution is also quite limited.

Mineralization

The mean annual precipitation in most parts of this basin is more than 40 inches. The soils of the basin have, therefore, been subjected to leaching action over a long period and much natural-occurring salt has been washed from them. Where natural drainage exists, the ground waters are of generally high quality. Even in this basin some minerals are present in excessive amounts at some locations. At several locations along the coast (near Eureka) ground water pumpage has caused sea water intrusion into the fresh water aquifers. In the northeastern part of this basin near the Oregon border, the climate is arid and ground water deterioration exists in several small areas in the Klamath River drainage. There are scattered locations of excessive total dissolved solids, boron, iron, and manganese. Limited measured data are available. Summaries of some measured data are presented in Table 12. Ground water mineralization in selected areas is discussed below.

In Scott River Valley, the ground water is generally magnesium or calcium bicarbonate in type, moderately to very hard, meets chemical standards for drinking water and is generally suitable for irrigation.


EEL RIVER
SACRAMENTO RIVER
SACRAMENTO
SAN FRANCISCO
SAN JOAQUIN RIVER
SALINAS RIVER
BAKERSFIELD
SANTA BARBARA
LOS ANGELES
RIVERSIDE
SAN DIEGO
AREAS OF MINERALIZED GROUND WATER
0 10 20 30 40 50 MILES

AREAS OF MINERALIZED GROUND WATER IN CALIFORNIA

FIG. 7

Table 12 Summary of Minerals in Ground Water at Selected Locations - North Coastal Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean, and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved Solids, mg/1			Chlorides, mg/1			Sulfates, mg/1			Total Hardness, mg/1			Boron, mg/1			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Scott River Valley	263	262	261	3	2	1	14	9	5	268	217	22	0.1	0.1	0.1	4	4	4
Eureka Plain	516	140	93	112	22	13	6	4	0	196	84	39	1.5	0.0	0.0	75	40	24
Eel River Valley	2756	572	194	1170	184	8	79	28	20	1102	306	149	0.1	0.1	0.0	41	25	9
Smith River Plain	161	140	114	33	24	8	4	1	0	122	60	23	0.0	0.0	0.0	42	28	12
Mad River Valley	418	219	70	92	18	11	21	1	0	249	130	21	0.5	0.0	0.0	78	33	10
Round Valley (Upper Eel River)	338	191	140	7	4	1	12	6	2	306	135	113	0.1	0.0	0.0	29	27	21

In the Eureka Plain, the ground water is bicarbonate in type with magnesium the predominant cation. The water is moderately hard and generally of good chemical quality suitable for most beneficial uses. In a few wells, the boron content is sufficiently high that the water is unsuitable for irrigation of most crops.

In the Eel River Valley, ground water is generally magnesium-sodium bicarbonate in type, of good chemical quality suitable for most uses. Higher mineral content is found near the Eel River estuary. Ground water in the Mad River Valley is moderately to very hard, and high chloride and total dissolved solids content along the coast gives evidence of sea water intrusion.

In Shasta River Valley and some of the upstream closed basins show total dissolved solids at some locations so high as to render the water unsuitable for various uses.

Iron

In the Smith River Plain, iron concentrations in excess of 0.3 mg/l (the limit for drinking water recommended by the U.S. Public Health Service) are found throughout the area. In the Mad River Valley, a high total iron concentration occurs throughout the valley. In Round Valley, the high iron concentrations render untreated water objectionable for domestic use.

SAN FRANCISCO BAY BASIN

This basin is a fast growing metropolitan area which has experienced intensive ground water development. Ground water is used for municipal, industrial and agricultural purposes. In areas immediately bordering the Bay, extremely high salt concentrations are found. The major metropolitan areas now import their water from great distances--mostly from the Sacramento, Mokelumne and Tuolumne River Basins. Much of the imported water is used to re-charge the aquifers being used as a ground water supply in the San Francisco Bay Basin, in an effort to "repel" the sea water intrusion which appears to be the major cause of the high salinity.

Mineralization

A summary of available 1965 measurements of mineral pollutants in ground water in a number of the sub-basins draining into San Francisco Bay is shown in Table 13.

The mineral quality of the native ground water of this basin is generally fairly good, except in areas where the ground water has been degraded by salt water intrusions. The water in this basin is quite variable in hardness, being soft in some locations and very hard in others.

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Table 13 Summary of Minerals in Ground Water at Selected Locations - San Francisco Bay Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean, and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved Solids, mg/l			Chlorides, mg/l			Sulfates, mg/l			Total Hardness, mg/l			Boron, mg/l			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Ukiah Valley	1280	207	137	518	7	4	55	6	0	277	132	76	63	0.1	0.0	86	23	12
Santa Rose	560	244	151	124	20	5	60	5	0	294	112	40	0.5	0.1	0.0	63	31	19
East Bay	4100	550	274	1480	88	12	452	52	15	2100	275	18	4.8	0.3	0.0	91	31	12
South Bay	1750	336	226	698	25	6	162	45	9	778	242	96	2.4	0.1	0.0	59	22	12
Livermore Valley	4700	554	368	2130	88	30	434	56	13	983	356	93	62	0.6	0.2	90	26	14
Petaluma Valley	19760	2384	127	10014	152	18	1066	32	3	8820	380	35	2.0	0.3	0.0	83	61	27
Napa Valley	1340	510	90	610	89	4	--	-	-	--	121	1	11	0.1	0.0	--	--	--
Sonoma Valley	660	300	270	129	43	17	48	6	5	149	64	17	4.8	0.9	0.0	92	74	24
Suisun-Fairfield Valley	2560	970	250	943	132	26	--	-	-	377	3191	93	18	1.2	0.2	79	45	34

In the Livermore Valley the ground water at some locations has become so highly mineralized that the state has established controls on saline discharges. A water softener business has moved out of the valley because it can no longer dispose of the regeneration water in the valley. Home-regenerated units are also being phased out (97). This is the result of the fact that there is no ground water leaving the valley at any time and wastes such as these degrade the ground waters, already high in total dissolved solids, even further.

Extremely high concentrations of dissolved solids have been recorded in Petaluma Valley, undoubtedly caused by sea water intrusions.

Nitrates

Excessive concentrations of nitrate have been measured in the Livermore Valley according to Dirker (97). Some wells in the Santa Clara Valley also indicate nitrate content in excess of 45 p.p.m. (98). It is presumed that other ground waters in this area also contain high concentrations of nitrate, especially since there are extensive urban areas and sewage and refuse disposal areas in this region, but no records of such concentrations are available to us.

CENTRAL COASTAL BASIN

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Surface drainage of this basin is quite limited. Because of the limited elevation of the mountains of these drainages, many of the surface streams are intermittent. None are snow-fed, and water supplies are very limited much of the time. As a result, the ground water supplies are generally preferred both for municipal and agricultural purposes. The ground water has been severely over-developed, as was pointed out in the previous chapter, and much of the surface water is used to re-charge the ground water aquifers. Several reservoirs on the surface streams of the basin function primarily for flood control and for temporary storage of waters which are used to replenish the ground water supplies. Approximately 90% of the water needs of this basin are met by ground water. Quality of the water varies greatly.

Mineralization

High concentrations of salt have shown up in a number of wells particularly in the Santa Ynez River Valley and in the inland Carrizo Area in the southern part of the basin. A summary of 1965 observations of some mineral constituents in the ground water is shown in Table 14.

In the Pajaro River sub-basin (99) there are many instances of wells showing chlorides in excess of 5000 p.p.m. The same is true for some of the coastal areas in San Luis Obispo County, with total dissolved solids also proportionately high (100, 101). Investigations in the Santa Maria River Valley (102, 103), in the Upper Salinas Basin (104),

Table 14 Summary of Minerals in Ground Water at Selected Locations - Central Coastal Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean, and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved solids, mg/1			Chlorides, mg/1			Sulfates, mg/1			Total Hardness, mg/1			Boron, mg/1			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Pajaro Valley*	1310	380	194	526	46	13	185	77	5	764	238	68	1.5	0.1	0	38	27	20
Gilroy-Hollister Basin	1480	770	250	381	88	15	463	239	170	1030	540	95	18	0.8	0	68	34	14
San Luis Obispo Hydrologic Unit	3024	688	92	1039	91	14	545	110	3	1151	405	35	0.64	0.08	0	69	28	6
Carrizo Hydrologic Unit	10460	1011	418	1525	73	31	5264	395	63	3150	423	143	16.5	0.85	0.1	88	50	25
Santa Maria-Cuyama Hydrologic Unit	5088	1506	250	374	42	7	2956	650	8	2656	922	15	2.5	0.23	0	36	19	14
San Antonio Hydrologic Unit	4070	693	385	1170	110	63	1022	136	11	1380	293	189	3.2	0.13	0.02	58	34	29
Salinas Valley	3134	550	222	890	89	12	1276	133	2	1483	324	70	2.5	0.2	0	59	35	18
Carmel Valley	729	462	252	159	67	26	131	103	68	425	273	146	0.1	0.1	0	40	31	26
Paso Robles Basin	3280	555	241	890	65	12	1276	131	7	1483	279	70	2.5	0.3	0	39	32	7
Santa Ynez Hydrologic Unit	21800	1035	288	11550	201	9	1653	262	0	4766	527	224	2.3	0.36	0.02	78	28	4
Santa Barbara Hydrologic Unit	2487	645	380	797	70	11	720	170	0	1119	363	161	7.7	0.21	0.01	30	30	17

* Does not include analyses of samples taken from wells in the areas of sea water intrusion, which show chloride content of several wells above 5000 p.p.m.

the Carmel River Basin (105), and in the Lompoc Basin (106) all report mineralization and other water quality problems.

Nitrates

Some excessive nitrates have been measured at many locations in this basin. More than 230 samples from about 100 different wells have shown nitrate concentrations in excess of 45 p.p.m. (107). Much of the nitrate moves with the soil moisture to the ground water as reported by Stout, et al (108).

Boron

Boron is not a great problem in this basin, with amounts toxic to agricultural plants only showing in a limited number of wells.

Fluoride

Very few samples of ground water indicate fluoride concentrations in excess of the minimum recommended values.

Other Pollutants

Ground water in the San Lorenzo River Watershed has been reported (109) to have a high iron content. This basin has a considerable amount of oil production. The activities associated with drilling and production of oil entail the handling of brines and waste oil. Undoubtedly there are instances of pollution from these sources, but the regulatory agencies maintain careful monitoring of these activities. No published reports of measured pollutants from these sources are available to us.

SOUTH COASTAL BASIN

The ground water in this basin is subject to heavy use and re-use. This basin includes the Los Angeles and San Diego metropolitan areas. The area is heavily dependent upon ground water supplies to supplement the imported water. Water is imported from the Colorado River and the Owens Valley (in the South Lahontan Basin). When the California Aqueduct is completed, water will also be imported from the Sacramento Basin.

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Mineralization

The accumulation of dissolved minerals in the ground water is one of the greatest problems of this basin. This basin is already subjected to more water quality management than any other part of the project area. Ground water replenishment has been practiced in this basin for many years, and at the present there are several fresh water "barriers" created by injection underground of water, relatively free of dissolved minerals, to serve as a barrier against sea water intrusion. Much of the water used for the barrier is storm drainage or domestic, industrial or agricultural waste water which has already been through the use cycle one or more times and may, itself, have a relatively high salt content. This exemplifies the problem which faces much of this basin, since the ground water is progressively accumulating more and more dissolved minerals. Mineral quality is quite variable throughout this basin. Near the ocean, many wells contain extremely high concentrations of dissolved solids, especially chlorides. A summary of minerals at selected locations as of 1965 is shown in Table 15. Many waters are extremely hard, as will be seen from the table. It should be noted that the information in the table represents measurements from many locations and is the result of an extensive monitoring system. This basin has probably been studied more thoroughly than any other part of the project area. Problems of mineralization are very critical in this basin. See (110) (111).

In the Santa Ana River Basin, the salt balance problems have been investigated quite thoroughly (112, 113, 114, 115). The limited ground water resources of the coastal plain south of the Santa Ana River Basin have been overdeveloped in several areas and the water quality has declined in a number of locations (116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126). Severe deterioration of water in Ventura County was evident as early as 1956 (127).

Boron

Excessive concentrations of boron exist at a number of locations throughout this basin. In some areas a high boron content is found near the coast, whereas in others, it is found in the inland valleys. It is a special problem in the Riverside-San Bernardino area. This area has in the past been a heavy producer of citrus fruit. Citrus is very sensitive to boron--some agricultural experts indicate that concentrations of 0.5 p.p.m. are toxic to some citrus varieties. Boron concentrations are increasing in the Riverside and other areas (128), and citrus production has decreased in recent years, partly due to the boron content of the water. Concentrations in excess of 0.5 p.p.m. exist at many localities.

Nitrates

Throughout this basin there are scattered instances of excessive nitrogen in ground water. Quite a number of samples indicate nitrates in excess of 45 p.p.m. However, it is not believed to be a general problem in any of the sub-basins, but rather a localized problem associated with a particular well at a particular time. In some areas of heavily fertilized agricultural land, as for example on some Riverside citrus land, quite high nitrates have been found moving into the ground water (129).

Table 15 Summary of Minerals in Ground Water at Selected Locations - South Coastal Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean, and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved Solids, mg/1			Chlorides, mg/1			Sulfates, mg/1			Total Hardness, mg/1			Boron, mg/1			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Mission Basin	13930	1740	709	6560	500	192	894	300	99	2532	883	366	0.80	0.17	0	75	38	21
San Dieguito Valley	27402	1956	271	13634	684	80	2536	419	25	9165	725	72	12.70	0.48	0.10	83	51	32
Tia Juana Valley	4680	2912	1099	1849	1012	346	944	348	186	1770	978	254	0.71	0.46	0.19	75	56	46
Oxnard Plain Area	33180	1050	289	15927	100	21	4538	381	33	8670	591	39	7.90	0.68	0.10	82	30	4
West Coast Basin	41397	620	176	22800	560	15	3280	290	0	8482	697	9	3.30	0.15	0.05	97	60	4
East Coastal Plain	41800	395	160	22270	60	10	2849	67	0	8792	228	14	7.20	0.07	0.02	94	37	17
Main San Gabriel Valley	1140	319	161	138	20	4	317	38	7	718	238	121	0.55	0.06	0	44	15	7
Chino Basin	1417	287	132	153	10	2	468	26	5	835	208	13	1.35	0.03	0	89	19	7
Perris Valley	11620	752	249	5960	259	49	643	38	5	4228	254	34	7.90	0.57	0.05	93	51	32

Fluorides

Fluoride concentrations in excess of one part per million have been found at a few scattered locations throughout this basin. Fluoride in ground water is not a major problem in this basin.

Gasoline

In September, 1968, gasoline was detected in a well at Forest Lawn Memorial Gardens in Los Angeles. Drilling and other tests confirmed that the gasoline pollution area was quite widespread and threatened many wells in the area (130). Details of investigation into the causes, and of the remedial action taken is given in the next section of this report.

Others

There are undoubtedly other pollutants in ground water of this basin. The waters of this basin are heavily used and re-used with much water being injected underground to increase the ground water supply. Under these conditions, the addition of pollutants is quite possible. However, no reports of other pollutants are available to us. Mineralization is a great problem, and far over-shadows the others.

SAN JOAQUIN BASIN

This is a large basin with an arid climate. The southern portion of the basin--the Tulare sub-basin--has very limited drainage to the north in most years. As a result, the mineralization of the ground is increasing with time. Imported water from the Feather River project, being of higher quality, may decrease the rate of degradation. Present and future expected drainage from the valley floor lands under irrigation is and will be of such poor quality that the water resource plans for the valley include a "master drain" to convey the drainage water from the valley, thus limiting the flow of drainage waters into the San Joaquin River. Ground waters of this basin show considerable fluctuation in quality, with the poorer quality resulting during times of drouth when the quantity of water is decreased.

Mineralization

The total dissolved solids in the ground water exceed the maximum permissible limits for many uses at various times at many locations throughout this large valley. Extreme hardness is a problem at many locations. High chlorides and total dissolved solids have been noted in the oil field areas north of Bakersfield near the Kern River. Excessive sodium content of the ground water is a problem in some areas. When the sodium is in exchangeable form it often presents a particular problem in irrigation and drainage of agricultural lands as described previously. A summary of limited information on the minerals in this basin as of 1965 is shown in Table 16.

It may be noted from the tabulated data that water in the Salt Slough-Los Banos Creek area has a rather high total dissolved solids content. Saline water from wells in the Stockton area was reported in 1955 (131).

Deep in the alluvium of the San Joaquin Valley there are bodies of highly saline old marine waters, referred to by some as connate waters. Not many wells go into this salty water, but the U.S. Geological Survey is preparing a report outlining the base of the fresh water in the valley. This report is expected to be available late in 1971 or early in 1972.

Boron

Boron is a problem at many locations in the San Joaquin Valley. Drainage water from the agricultural lands in the west side of the valley often contain as much as 10 to 15 p.p.m. of boron. There is also a boron problem on the east side of the valley near Bakersfield. The boron problem is usually greatest in waters derived from or associated with the coastal range of mountains (132).

Nitrates

The San Joaquin Valley is heavily fertilized. It is a rich agricultural area, but the drainage waters, especially on the west side of the valley, are highly mineralized and often contain high boron as mentioned above. These waters also contain high nitrate concentrations. Most of these pollutants percolate with the water into the deeper ground water aquifers of the valley, and thus have considerable effect on the water quality. According to Pratt (129), the nitrogen is not tied up in the soil (by nitrification) except in the surface organic layer. The nitrates move into the ground water along with other dissolved constituents. Heavy nitrate concentrations have shown up in the area around Fresno. Doneen (133) reported on presence and movement of nitrates into the ground waters. High nitrate concentrations have been reported in the Fresno area (134, 135) and in the Delano area (136).

Arsenic

In a relatively small area west of Fresno, arsenic has been found in the ground water in an amount up to ten times the limit recommended by the U.S. Public Health Service. Lofgren (137) believes that the arsenic in this area was forced out of deep clays compressed by the action of land subsidence in this particular area. A considerable subsidence problem does exist at this location. Lofgren has been involved in studies of the land subsidence here for many years.

Table 18 Summary of Minerals in Ground Water at Selected Locations - San Joaquin Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved Solids, mg/1			Chlorides, mg/1			Sulfates, mg/1			Total Hardness, mg/1			Boron, mg/1			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
San Joaquin County	3840	548	170	1640	58	3	435	28	1	1430	110	47	2.1	0.5	0	88	43	18
Crows Landing-Newman Area	-	877	-	-	78	-	-	283	-	-	-	-	-	0.5	-	-	35	-
Gustine Area	-	533	-	-	55	-	-	101	-	-	-	-	-	0.41	-	-	11	-
Salt Slough-Los Banos Creek Area	-	1368	-	-	425	-	-	457	-	-	-	-	-	2.4	-	-	78	-
Los Banos Area	-	498	-	-	97	-	-	85	-	-	-	-	-	0.38	-	-	49	-
Dos Palos Area	-	801	-	-	355	-	-	79	-	-	-	-	-	0.33	-	-	55	-
Firebaugh Area	-	368	-	-	91	-	-	53	-	-	-	-	-	0.15	-	-	67	-
San Joaquin Basin	6400	282	45	3730	35	1	542	11	0	3900	115	7	2.6	0.0	0.0	95	38	4
Tulare Basin	6450	713	148	3490	71	8	1620	133	2	3190	220	6	17.0	0.4	0.0	93	48	6

Other Pollutants

In the San Joaquin Valley there are extensive agricultural enterprises. Many of the crops are heavily dusted or sprayed with various pesticides. One big problem associated with dusting and spraying is the disposal of the pesticide containers. This causes a potential hazard because of the concentrated materials used and if containers are not carefully disposed of, the pesticide residue is sometimes a serious problem, according to Carnahan (138). Some sewage spraying in the Mokelumne River drainage by small communities poses a potential problem which is not serious (139).

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SACRAMENTO BASIN

Ground water in this basin is generally of excellent quality and suitable for most uses. This basin is a heavy water producing area, providing a great excess of water that is wasted in the San Francisco Bay. Most areas have ample water supplies for the present and future, and the waters have not been degraded by extensive over-use as has been the case in many areas. However, the total use of ground water in this basin does exceed the "safe yield", and there are areas of local shortages and diminishing water quality.

Mineralization

The dissolved solids content of the waters of this basin generally is less than 500 p.p.m., but there are locations where total salts have been recorded at over 2700 p.p.m. The predominant water type is calcium bicarbonate, but sodium and magnesium are present in significant quantities at some locations. A summary of minerals in the ground water at selected locations as of 1965 is given in Table 17.

Boron

Boron is moderately high in some areas in this basin. Measurements as high as 13 p.p.m. have been recorded. This is many times more than the toxic limit for most plants.

Nitrates

There are no serious nitrate problems in this basin, according to Carnahan (138). Localized problems may exist at some locations, depending on sewage and solid waste disposal practices and other conditions.

NORTH LAHONTAN BASIN

Ground water in this basin is not developed extensively. The basin itself is small, as already previously described. Only three ground water sub-basins are recognized (1) Surprise Valley (near Cedarville in

Table 17 Summary of Minerals in Ground Water at Selected Locations - Sacramento Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved Solids, mg/1			Chlorides, mg/1			Sulfates, mg/1			Total Hardness, mg/1			Boron, mg/1			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Redding Basin	2070	129	41	908	3	8	-	-	-	118	71	16	13.0	-	0.3	-	-	-
Alturas Basin	584	178	98	-	-	-	-	311	-	515	68	7	-	-	-	-	-	-
Tehama County	313	193	107	-	5	-	-	16	-	272	116	62	0.4	0.2	0	-	9	-
Glenn County	618	298	107	118	30	6	-	59	-	348	198	113	-	-	-	-	-	-
Sierra Valley	1390	182	118	349	23	0	383	4	0	466	66	13	5.8	0	0	91	46	11
Butte County	1610	260	108	269	10	2	696	4	0	357	153	55	5.3	0	0	90	17	11
Colusa County	877	328	148	132	45	8	101	12	0	367	183	57	0.5	0.2	0	80	38	18
Sutter County	2790	447	99	1370	17	3	262	18	0	341	234	69	0.9	0.1	0	81	23	9
Yuba County	952	205	168	325	15	6	57	7	0	366	89	11	0.5	0	0	63	29	13
Placer County	390	204	118	56	16	5	-	-	-	208	34	39	-	-	-	-	-	-
Yolo County	1920	490	245	607	21	7	458	43	0	1260	274	43	5.4	0.9	0.1	81	34	12
Sacramento County	997	204	137	435	12	1	26	2	0	344	98	47	2.0	0	0	-	-	-

the extreme northeastern corner of California) (2) Honey Lake Valley (near Susanville) and (3) Bridgeport Valley (near Bridgeport).

Mineralization

Ground water in this basin is of generally good quality. The water contains excessive sodium at a number of locations. Water ranges from soft to very hard depending on location. A number of mineralized hot springs exist in the Bridgeport area. Summary of a limited number of measurements of mineral quality are given in Table 18.

Boron

Boron in excess of 2 p.p.m. occurs at a number of locations in all three ground water areas.

Fluoride

Fluoride in excess of the U.S. Public Health Service recommended limit is found at a number of locations in this basin.

Nitrates

Nitrates in excess of 45 p.p.m. are found in some wells in Honey Lake Valley.

Arsenic

Increasing arsenic concentrations have been found in a number of wells (6). State and County Health Departments have conducted a survey to determine the extent of arsenic degradation.

SOUTH LAHONTAN BASIN

This basin is relatively small, but highly arid. In a general sense the ground water of this basin is good, but there are many wells which exhibit poor quality characteristics.

Mineralization

The mineral quality of ground waters in this basin is quite variable. A total of 120 wells in the Antelope Valley Hydrologic Unit and 79 wells in the Mojave Hydrologic Unit were sampled in 1965. A summary of the results of mineral analysis of these samples is shown in Table 19. Most wells have water of reasonably good quality, but a number have undesirable characteristics (140, 141). Near the town of Boron, the quality is poor with total dissolved solids in excess of the limit for drinking water. Sodium concentrations are also excessive in a number of wells.

Table 18 Summary of Minerals in Ground Water at Selected Locations - North L[illegible]ntan Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved Solids, mg/l			Chlorides, mg/l			Sulfates, mg/l			Total Hardness, mg/l			Boron, mg/l			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Surprise Valley	2000	200	90	403	4	0	564	6	1	816	90	10	5.4	0.1	0.0	82	31	21
Honey Lake Valley	1350	219	170	520	11	3	418	7	0	1480	65	11	3.6	0.3	0.0	90	41	1
Bridgeport Valley	2030	250	74	129	15	0	-	235	-	311	154	36	-	0.3	-	-	42	-

Table 19 Summary of Minerals in Ground Water at Selected Locations - South Lahontan Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved Solids, mg/l			Chlorides, mg/l			Sulfates, mg/l			Total Hardness, mg/l			Boron mg/l			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Antelope Hydrologic Unit	2100	273	124	960	20	4	480	60	7	454	120	17	10.80	0.14	0	94	46	4
Mojave Hydrologic Unit	2266	414	22	555	46	1	731	110	0	744	159	8	5.50	0.19	0	96	47	6

Boron

A number of wells in the basin have boron concentrations above 2 p.p.m., including most of the wells in the vicinity of the town of Boron.

Fluoride

Fluoride in excess of the limit for drinking water is found in a number of wells in the basin.

Arsenic

Excessive amounts of arsenic have been reported in some wells. In the North Muroc basin, wells along the north edge of the basin penetrate aquifers in which naturally-occurring arsenic if found. The U.S. Public Health Service has a recommended upper limit of 0.01 mg/l of arsenic in public water supplies and a maximum allowable of 0.05 mg/l. In the vicinity of Edward's Air Force Base a detailed study of arsenic content of waters in this area (142) showed that from 32 samples of surface drainage water, all except two exceeded 0.1 mg/l, with the highest concentration being 20 mg/l and many over 1.0 mg/l. Wells in the area have a high potential hazard related to the arsenic.

Other Pollutants

In June, 1970, a detailed study of ground water quality in the vicinity of Barstow was completed (143, 87). This study indicated that a number of wells were polluted with detergents, phenols, hexavalent chrome, phosphate and ammonia nitrogen showing up in a number of samples taken.

COLORADO DESERT BASIN

This basin includes three ground water sub-basins. The most significant is the Coachella Valley (known as Whitewater Hydrologic Unit), the Dale Hydrologic Unit (the vicinity of the community of Twentynine Palms), and the Lucerne Valley, just east of Victorville--most of the development is in the Coachella Valley.

Mineralization

A summary of sampling in 1965 for mineral quality of the ground water is shown in Table 20. Water in the Coachella Valley is quite good quality, but in the Lucerne Valley (a "sink" area) three wells of 22 sampled showed a highly mineralized sodium chloride water. Other wells in the valley are generally suitable for irrigation and drinking water. Water in the Dale Unit is generally good, but two wells indicated high mineralization, and also a high sodium content.

Table 20 Summary of Minerals in Ground Water at Selected Locations - Colorado Desert Basin Adapted from Water Resources Council Report (6), data as of 1965. H, M, and L refer to high, mean and low values from original report. The number of tests used in calculation of the mean is not available.

Location	Total Dissolved Solids, mg/l			Chlorides, mg/l			Sulfates, mg/l			Total Hardness, mg/l			Boron, mg/l			Sodium %		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Lucerne Hydrologic Unit	10140	637	231	4850	79	5	66	34	9	1365	259	21	14.28	0.08	0.02	95	33	13
Dale Hydrologic Unit	1490	360	156	235	30	9	595	82	6	185	48	38	2.16	0.17	0.07	92	68	61
Whitewater Hydrologic Unit	1080	420	101	143	22	6	324	132	9	477	164	18	1.54	0.08	0	87	47	11

Boron

In the Lucerne Valley and the Dale area several wells yielded water with boron in excess of 2 parts per million.

Fluoride

In the Dale area, one well had excessive fluoride.

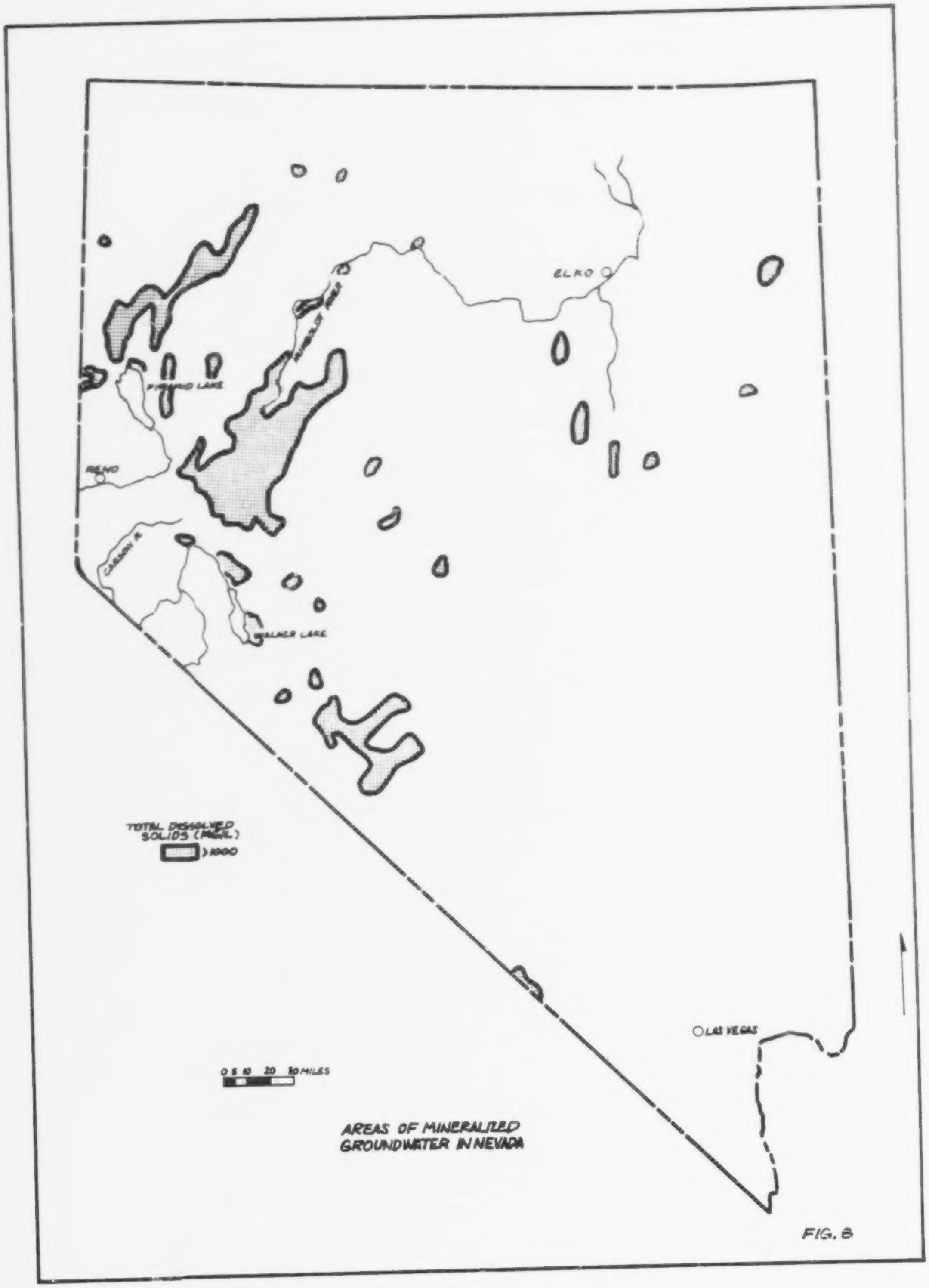
Nevada

The principal problem with ground water pollution in Nevada is mineralization of the ground water. Many of the ground water basins are closed basins so that evaporation tends to cause soluble salts to accumulate at the ground surface where recharge waters carry the dissolved salts into the groundwater reservoir. The ground water extracted near the center of the closed basins is often rather highly mineralized. The total area underlain by ground water exceeding 1000 mg/l of dissolved salts is shown in Figure 8. This area very likely exceeds 2 million acres having a specific yield or a drainable volume of 15%. The total volume of mineralized water, exceeding 1000 mg/l of dissolved solids in the first 100 feet of the ground water reservoir is a total of 300 million acre feet of water in the state of Nevada (15).

Nevada can conveniently be divided into six hydrologic basins (Figure 4) which are as follows: (1) Humboldt (29,900 sq. mi.) which covers the northern part of the state, had a population of 27,600 in 1965. (2) Central Lahontan (9,800 sq. mi.) which covers the Truckee River Basin and the West Central section of the state, had a population of 166,400 in 1965. (3) Tonopah (44,300 sq. mi.) which covers the central and the south central portion of the state, had 8,300 people in 1965. (4) Nevada has a portion of the Lower Colorado River (17,100 sq. mi.) in the southeast corner of the state. Part of the Great Salt Lake Basin (4,200 sq. mi.) and the Snake River Basin (5,100 sq. mi.) are in Nevada. These basins are shown on Figure 4.

Most of the 253 ground water basins are small closed valleys in alluvial deposits in the valley. The ground water quality in these valleys range from fresh to very saline as explained at the beginning of the section on mineralization. There are only two places in the state where the total dissolved solids in the ground water exceed 10,000 mg/l, and these are small point sources in the Tonopah Basin in Soda Spring Valley and Clayton Valley a few miles south and east of Walker Lake. One spring runs about 15,000 mg/l and the other is almost 30,000 mg/l but both are just seepage flows that probably do not have a significant effect on the local ground water.

In some areas the amount of total dissolved solids may not be the limiting pollutant for water use. There may be excessive quantities


ELKO
PYRAMID LAKE
HUMBOLDT RIVER
RENO
CARSON R.
WALKER LAKE
TOTAL DISSOLVED SOLIDS (MG/L)
>1000
LAS VEGAS
0 5 10 20 30 MILES

AREAS OF MINERALIZED GROUNDWATER IN NEVADA

FIG. 8

of a single element or compound which may be the limiting factor for water use. For example, such elements or compounds as boron, fluoride, manganese, iron, sulfate, nitrate, chloride, and others are sometimes toxic at very small concentrations so a critical amount of any one of these may be a limiting factor on the use of the water. There are several local areas in the region where the presence of one of these toxic elements or compounds is the limiting factor on the use and development of the ground-water supply.

The suitability of water for irrigation may be evaluated on the basis of salinity hazard, sodium (alkali) hazard, and the concentration of bicarbonate, boron, and other ions. The salinity hazard depends on the total dissolved solids and is normally measured in terms of electrical conductivity with units of micromhos per centimeter. Nearly all irrigation waters, which can be used for any length of time, have conductivity values of less than 2250 micromhos per centimeter. The sodium (alkali) hazard is expressed by the sodium-absorption ratio (SAR) and it represents the relationship between the cations of sodium and the cations of calcium and magnesium. If the proportion of sodium among the cations is high, the alkali hazard is high but if calcium and magnesium predominate, the alkali hazard is low. An SAR in excess of 10 will generally represent a sodium hazard in fine grained soils.

In the case of the bicarbonate ion, the measure of a hazardous level of concentration is given by the residual sodium carbonate (RSC).

$$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$ in which concentrations are expressed as equivalents per million.

If the residual sodium carbonate (RSC) is greater than 2.5 epm (equivalents per million), the water is not suitable for irrigation. Most natural waters contain boron and boron is essential to the growth of all plants but the quantity required is very small. In general, boron in excess of 3 mg/1 (milligrams per liter) is injurious to most crops, and much smaller amounts may be toxic to certain crops.

There are two areas of high population concentration in Nevada, the Reno-Carson City area and the Las Vegas area. Municipal wastes are used to charge the ground water in the Las Vegas area but there are no indications in either of the areas of coliform pollution of the ground water. There have not been any organic pollution problems in the ground water so far in the state although there are some potential problems in the highly populated areas.

Nevada is not a very highly industrialized state but there is some industry and it makes a major contribution to the economy of the state. There have been no indications so far that there is any problem with pollution of ground water from industrial wastes. Neither pesticides nor commercial fertilizers have been a problem anywhere in the state.

The atomic testing in Nevada has been done in the Tonopah Basin which is very sparsely populated. No indicators of nuclear pollution have been measured in the ground water in that part of the state so it is felt that so far the atomic testing has not created any ground water pollution problems.

In summary, there are many areas in Nevada where the ground-water is not very satisfactory for domestic use or for irrigation. The limiting condition may be one or a combination of the factors discussed in the previous paragraphs so that in order to develop the ground-water supplies in many valleys of Nevada, solutions must first be found to the numerous problems of mineralization. With this general summary of the mineralization problems in Nevada, the following sections will give a more detailed description of the mineralization problems as they exist in each of the six hydrologic basins in Nevada.

HUMBOLDT BASIN

Ground water in the principal aquifers in most basins in the Humboldt basin is fresh and in many places contains less than 500 mg/l of dissolved solids. Notable exceptions are the Smoke Creek, Desert Creek, and Black Rock Deserts in the lower Quinn River basin and the Lovelock area in the lower Humboldt River basin, where water from most aquifers is saline. In these areas, the dissolved-solids content of the water ranges from about 1,000 mg/l near the margins of the valleys to more than 3,000 mg/l in the central portions. Stagnation in sedimentary deposits containing large amounts of soluble salts is the principal reason for the high mineral content of the ground water, but evapotranspiration and recycling of irrigation water also raise the mineral content of the water in shallow aquifers. The waters are mostly sodium bicarbonate and sodium chloride in type and locally contain moderate to large amounts of fluoride and boron among the minor constituents. Fresh ground water probably occurs at the very edges of the desert areas near the mouths of some of the larger streams.

The principal aquifers in several other valleys in the Humboldt basin contain saline water, at least locally. For example, two wells in the northern part of Pine Valley produced water containing nearly 4,000 mg/l of dissolved solids from depths of about 400 feet. There appears to have been no outlet from Pine Valley during the Tertiary Epoch and the sediments tapped by the wells apparently contain soluble salts. Similar conditions may also exist in Huntington Valley, although water from two wells in the valley is fresh. In the southern part of Duck Lake Valley near the south ends of the Kings River and Quinn River valleys, and the north end of Grass Valley, some aquifers locally contain slightly saline water. Although the ground water in Desert and Silver State Valleys is fresh, the dissolved-solids content of the water in most places apparently exceeds 500 mg/l; near the lower ends of the valley, it may exceed 1,000 mg/l in some aquifers. Also, the boron and fluoride content of ground water from several sources in Desert Valley is relatively high.

Another area of high mineralization is located in San Emidio and the Smoke Creek Deserts (144). These areas are located just north of Pyramid Lake. Of twelve wells tested in this area in 1966, most of the samples indicated high salinity and alkalinity hazards. The results varied over a rather wide range but it appears that much of the ground water in this area is of poor quality for agricultural purposes. In summary, the San Emidio Valley, the Smoke Creek Valley, the Lower Humboldt River Valley, and Pine Valley probably contain over 90% of the slightly saline (1000 to 3000 mg/l) and moderately saline (3000 to 10,000 mg/l) ground water in the Humboldt Basin. In turn, this region contains in the upper 100 feet of the ground-water reservoir about 25% to 30% of the mineralized ground water supply in the state. This is approximately 8 or 9 million acre feet of ground water with a dissolved salt content exceeding 1000 mg/l.

CENTRAL LAHONTAN BASIN

Most of the saline ground water in this basin is found in the Carson Sink area. The dissolved-solids content of the water in this area ranges from 1000 mg/l to well over 3000 mg/l including large amounts of sodium, chloride, sulfate, and bicarbonate and relatively large concentrations of the toxic ions such as boron, fluoride, and arsenic.

The Walker Lake area has ground water exceeding 1000 mg/l of dissolved solids in many parts of the Walker River Valley but most of the ground water in that valley is classified as fresh water. The mineralized water generally comes from the shallow wells and the deeper aquifers contain good water.

There is also another area of saline ground water located due east of Pyramid Lake about 10 miles or so. The salt concentrations in this area run from 1000 to above 3000 mg/l and the area involved is around 30,000 acres.

These three areas of Carson Sink, Walker Lake, and east of Pyramid Lake contain about 50% to 60% of all the mineralized ground water (> 1000 mg/l) in the entire state of Nevada. There are in this region about 1,200,000 acres of land underlain by ground water with dissolved salt concentrations exceeding 1000 mg/l.

In order to develop the ground water potential of this subregion, research will be required to find users who can tolerate high salt concentrations or to develop an economical means of treating the water.

The western side of this basin has a fresh ground water supply but there are a few minor elements such as iron which cause some problems

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at restricted locations in the region. Eagle and Washoe Valleys generally contain ground water with less than 500 mg/1 of dissolved solids in the ground water.

TONOPAH BASIN

Ground water in principal aquifers in most valleys in the Tonopah Basin is fresh, and in many valleys, the water contains less than 500 mg/1 of dissolved solids. In the Clayton-Fish Lake Valley areas south of Tonopah, much of the ground water is moderately to very saline as is most of the water in the lower part of the Amargosa Desert.

Many of the valleys in the Tonopah Basin are topographically closed, and therefore, water in the shallow aquifers beneath the mudflats or playas at the lower ends of these valleys probably is saline. Deeper aquifers in the lower parts of most of these topographically closed valleys, however, probably contain fresh water. One known exception is in the lower parts of Steptoe Valley, where the deeper fill deposits may contain large amounts of soluble salts.

Ground water in the northeastern part of the Tonopah Basin, where carbonate rocks predominate, is generally of a calcium magnesium bicarbonate type. In the southern and southwestern parts of the basin, where tuffaceous volcanic rocks predominate, the water is mostly sodium bicarbonate, sodium chloride, or mixed type.

The ground water in many of the valleys in the southern part of the Tonopah Basin contains relatively large concentrations of fluoride, which apparently are derived from the volcanic rocks in this part of the region. Relatively large concentrations (one to 13 mg/1) of fluoride occur in parts of the Amargosa Desert, the Sarcobatus Flat-Oasis Valley areas, Gabbs Valley, and Fish Lake Valley.

GREAT SALT LAKE BASIN

Only a small part of this basin lies in Nevada and most of the ground water is fresh. There are some small areas just north of Wendover, Utah, where the salt concentrations exceed 1000 mg/1. The area is located on the western edge of the Great Salt Lake Desert in a very sparsely populated region.

LOWER COLORADO RIVER BASIN

The major part of the ground water in this area has less than 1000 mg/1 so that it is classified as fresh water. There are a few thousand acres north of Lake Mead that are underlain by mineralized waters ranging from 1000 to 3000 mg/1. Some of these ground waters are saline because the natural aquifers contain large amounts of soluble salts. The ground water table averaged a decrease in elevation of 10 feet per year from 1960 to 1965 in the Las Vegas area. The water is being mined but the degeneration of ground water quality is not yet very severe in this basin.

SNAKE RIVER BASIN

This area in Nevada is very sparsely populated and the average elevation is over 5000 feet above mean sea level. Cenozoic volcanic and sedimentary rocks occupy about 85% of the total area. Most of the rocks have a rather limited capacity to transmit water. In the upper 100 feet of saturated rock, the ground water storage exceeds 15 million acre feet. Much of the water, however, could not be recovered economically and in areas it may not be chemically suited for many uses. Although the water quality data for this area are very limited most of the well samples available indicate that the water is generally within the following ranges (145):

Salinity Hazard - low to medium

Sodium Absorption Ratio - 0.1 to 2.0 with most samples below 1.0.

Sodium Hazard - All samples low.

Total Dissolved Solids - 45 to 205 mg/1.

The toxic ion concentrations are also very low so that most of the ground water in this area appears to be of relatively high quality for most uses.

Utah

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The ground water in Utah is generally of fairly high quality and in many areas it has not been used very extensively. Legal restraints in the past have made it difficult to develop the ground water resources in Utah. Until 1969, Utah Courts generally held that the owner of a discharging well was liable for damages resulting in serious reduction of water level, artesian head, or discharge in wells with earlier water rights. The effect of this policy was to limit the development of the ground-water resources. In 1969, however, the Utah Supreme Court reversed a lower court decision in the following way:

> "there has come to be recognized what may be referred to as the 'rule of reasonableness' in the allocation of rights in the use of underground water. This involves an analysis of the total situation: the quantity of water available, the average annual recharge in the basin, the existing rights and their priorities. All users are required where necessary to employ reasonable and efficient means in taking their own waters in relation to others to the end that wastage of water is avoided and that the greatest amount of available water is put to beneficial use."

> In a specific reference to the maintenance of natural artesian pressure, the court also stated: "We perceive nothing in our statutory law *** which compels a conclusion that owners of rights to use underground water have any absolute right to pressure." (146)

This decision should help open up the development of ground water in Utah. The optimum development of the total water resources can occur only under unified or correlated management between surface and ground-water supplies.

In developing Utah ground-water resources, the principal water quality problem is the mineralization of the ground water. The mineralization problem is rather extensive (Figure 9), but it is not as severe as in other states of this region because the poor quality water underlies desert or mountainous areas where the population [illegible] very low.

The mineralization of ground water in Utah is generally the result of the following factors: (1) Solution from natural rocks, (2) Highly mineralized waters leaking into aquifers from fault zones, (3) Agricultural waste waters including irrigation return flows, (4) Evapotranspiration, and, (5) a few other miscellaneous processes. The ground water quality in the areas of high use is generally very good. The large area west of Salt Lake City of poor quality shown on Figure 9 is a desert area of the state where there is little or no population. The other area of poor ground water quality is on the Colorado Plateau where the ground water supply is very limited.

UPPER COLORADO RIVER BASIN

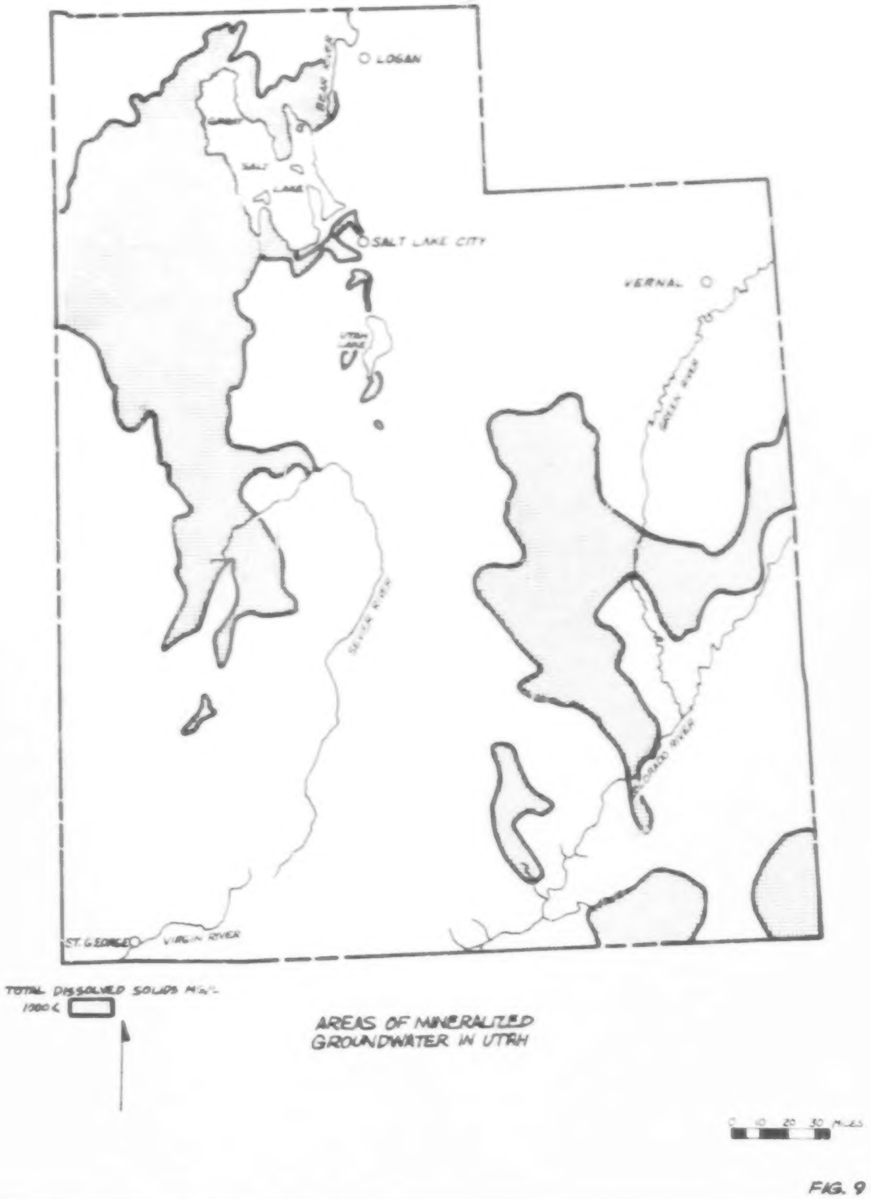
Most of the ground water in this basin has a total dissolved solids concentration of less than 1000 mg/1. However, there are extensive areas in the Price, San Rafael and the Dirty Devil River basins where the total dissolved solids in the ground water exceeds 1000 mg/1. Most of the low quality ground water is found in Emery and Grand counties of Utah. One rather extensive area of poor ground-water quality is also found in Uintah County as shown in Figure 9.

Except for the Dirty Devil River basin, the sodium-adsorption ratio is between 5 and 10 for all of the above areas of high total dissolved solids.

The present use of ground water in this region is very small and the present effects of pollution are minor. However, the ground-water does represent an important future resource and much needs to be learned about this resource before it can be developed and managed wisely.

GREAT BASIN

Most of this area is underlain by deep deposits of porous alluvial fill


O LOGAN
BEAR RIVER
GREAT
SALT
LAKE
O SALT LAKE CITY
UTAH LAKE
VERNAL O
GREEN RIVER
SEVIER RIVER
COLORADO RIVER
ST. GEORGE O
VIRGIN RIVER
TOTAL DISSOLVED SOLIDS MG/L
1000<
0 10 20 30 MILES

AREAS OF MINERALIZED
GROUNDWATER IN UTAH

FIG. 9

which contains large quantities of fresh ground water. In the Bear River Basin in the north end of the Great Basin, the major part of the ground water contains less than 1000 mg/l total solids. In the upper part of the Bear River basin the ground water is of the calcium magnesium bicarbonate type, whereas most of the ground water in the lower basin is of the sodium chloride or sodium bicarbonate type.

There are a few local areas in the Bear River basin where the ground water is slightly or moderately saline. The main factors affecting the poor quality in some of these areas are probably the following: stagnation of water in fine grained deposits containing soluble salts, evapotranspiration, recharge with saline irrigation return flow and lateral movement of water into aquifers from areas of large thermal springs.

Nearly all of the ground water in the mountain valley east of Great Salt Lake and Utah Lake is fresh. Most principal aquifers to the east of Great Salt Lake and the Tooele and Jordan valleys contain fresh water. The ground water basin west of Great Salt Lake is highly mineralized with salt concentrations exceeding 3000 mg/l in many parts of this area. The ground water basin along the borders of the north end of Great Salt Lake is also highly mineralized. The lower end of the Sevier River basin contains large areas underlain by ground water of poor quality (1000 mg/l or more). This area of the Great Salt Lake Desert and the Sevier Desert covers an area of roughly 5 million acres and most of the ground water exceeds total dissolved salt concentrations of 1000 mg/l. It is estimated that over 2 million of those 5 million acres are underlain by ground water exceeding salt concentrations of 3000 mg/l. The ground water in most of this area has a high sodium content with sodium adsorption ratios exceeding 10. This means that much of the ground water in the area west of the Great Salt Lake is of questionable quality for most irrigation uses. Not many ions, which are often considered to be toxic, have been identified in this area. However, in the upper and middle Sevier River basin, the fluoride content exceeds three milligrams per liter and is as high as six mg/l. These relatively large concentrations of fluoride are probably derived from rocks of volcanic origin which underlie much of this basin.

LOWER COLORADO RIVER BASIN

This area in Utah covers about 3000 sq. miles. The ground water in the area is almost all high quality with a salt content of less than 1000 mg/l. There are no significant pollution problems in the ground water in this area.

In summary of the mineralization problems in Utah, there are large areas in the state where the ground water has a salt concentration of over 1000 mg/l. Most of these problem conditions exist in areas of very low rainfall, limited population, and limited quantities of ground water. If this water is ever to be used for beneficial purposes, economical means of desalinization will have to be developed. Many of the water quality problems are located in areas where the land is not very suitable for growing things and so it is likely that any development in many of these places might have to be for industrial purposes. In connection with the mineralization problem, most of the dissolved solids consist of the following ions or groups of ions (calcium, magnesium, sodium plus potassium, chloride, bicarbonate and sulfate). In the areas surrounding the Great Salt Lake and especially on the west side of the lake, there are many areas where the ground water is saline. All the valleys that drain directly into Great Salt Lake and the Great Salt Lake Desert contain saline ground water at their lower ends. In a number of these valleys the total dissolved solids increase markedly with depth. For example, in Sink Valley on the edge of the Great Salt Lake Desert, the ground water has a concentration of total dissolved solids of about 3600 mg/l at a depth of 225 feet. This increases to 49,000 mg/l at a depth of 675 feet. The west side of Great Salt Lake and most of the Great Salt Lake Desert have ground water which exceeds 3000 mg/l. This area is probably the only area in the state which has large quantities of poor quality ground water. The toxic ions such as boron, fluoride, heavy metals, and others are not known to be a problem anywhere in the ground water of the state. Pesticides are not known to be a problem and neither are the nitrates and phosphates. Although BOD and coliform organisms are potential problems in a number of places, these pollutants are filtered out rather effectively as the water passes through the soil. Therefore, organic and biological pollutants are not known to be a serious problem anywhere in the ground waters of Utah. If they are problems, there have not been adequate measurements made to determine their extent.

SECTION VI

CONDITIONS CAUSING GROUND WATER POLLUTION

In the previous section, the measured indicators of ground water pollution were discussed, and the indicators found in each of the subbasins of the project area were summarized. No attempt was made to signify the cause of the pollution, but only to register the fact that some degree of pollution does exist.

During the course of the investigation being reported herein, many existing and potential causes of pollution of the ground water were made known to us. Often water of poor quality is caused by several factors--even a combination of a number of physical conditions. Indeed, in many instances, an existent pollution condition may have several contributing sources. In this section, various conditions, circumstances or activities which have had a known or suspected polluting effect on ground waters are listed. The following list is a fairly good summary of most of the conditions which cause pollution of ground water. They are listed approximately in the order of their significance as causes of ground-water pollution in the project area:

1. Natural leaching
2. Irrigation return flow
3. Sea water encroachment
4. Solid wastes
5. Disposal of oil field brines and other materials
6. Animal wastes
7. Accidental spills of hazardous materials
8. Water from fault zones and volcanic origin
9. Evapo-transpiration of native vegetation
10. Injection wells for waste disposal
11. Fertilization of agricultural lands
12. Land disposal of wastes--municipal and industrial
13. Seepage of polluted surface waters
14. Urban runoff
15. Connate water withdrawal
16. Mining activities
17. Aquifer interchange
18. Mineralization from soluble aquifers
19. Crop residues and dead animals
20. Pesticide residues
21. Land subsidence effects on water quality
22. Other causes

Each of the above processes is a potential cause of ground water pollution in the four states of the project area. In many instances it is difficult or impossible to positively identify a given act or set of acts or circumstances as the cause of a given known pollution. Nevertheless, the following discussion of each of the causes listed above

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is presented to assist in the development of a better understanding of the factors which cause pollution of ground water. In most instances we also list the location or locations where these actions or conditions are known or suspected to have a polluting effect on the ground water.

Natural Leaching

Throughout the project area, most of the ground and surface waters contain some natural dissolved salts. These dissolved salts have their origin in the soils and rocks of the watershed areas. The presence of these minerals in the soil and rocks is directly related to the climate as has already been explained. The natural accumulation of these minerals is greatest in the areas of low precipitation, and especially those areas where natural drainage is restricted. Precipitation percolating through the salt laden soils and rocks takes some of the salt into solution and carries it into the ground water. In areas where the ground water is near the land surface; evaporation and transpiration of the ground water, which leaves the salt on the surface, further concentrates the salt in the waters which are left behind.

Natural leaching may also take place within a water bearing aquifer. Often the water, as it moves through an aquifer, dissolves soluble minerals from the aquifer material itself or from its confining formations. Natural leaching causes degradation of the ground water in all parts of the study area. It is most intensified in the areas of lowest precipitation where the soil contains high concentrations of dissolved minerals--especially the desert portions of the project area where natural drainage is restricted and heavy accumulations of salt are found in the soil. In the Great Salt Lake Desert, for example, waters percolating through the salty soil have resulted in ground waters high in salts. In the mountainous portions of the study area the greater quantities of precipitation leach salts out of the soil, but in smaller quantities. The greater quantities of precipitation also tend to dilute the salty waters so that the salt content in many locations near the mountains is not excessive.

The usual ground water pollution problems related to natural leaching involve the more common salts found in soil and water, especially in the arid regions. There are locations, however, where a particularly toxic element occurs naturally and gets into the ground water. Examples are the boron at many locations in the project area, and the arsenic in Kern County, California (138, 142).

Irrigation Return Flow

In the arid west where irrigation is necessary for growing crops, the salt content of the ground water has been increased by irrigation practices. Much of the water applied to the soil is evaporated by the sun thus leaving the dissolved minerals on or near the surface of the land.

Unless excess water is applied to the land, these minerals will accumulate in the soil and will inhibit the growth of plants. For this reason, irrigated lands must be flushed out occassionally by excessive applications of water to the land. This is usually automatically accomplished in normal irrigation practice because of the difficulty of distributing the irrigation water at an efficiency of greater than about 50%, (unless the irrigation water is applied by sprinkling -- Israelsen and co-workers found an average of 38% efficiency on selected Utah farms (147)). The surplus irrigation water applied seeps into the soil and often passes down into the ground-water reservoir. It leaches the accumulated salts out of the soil and carries them into the ground water, thereby building up the salt concentration in the ground water. In addition to the natural salts in the soil, there are often nitrate and phosphate fertilizers applied to the soil so that some of these substances are also carried into the ground water. Nitrates, especially, become a problem in some areas. It should be noted that a large part of the irrigation return flow finds its way into the ground water. Irrigation return flow has many pollutional effects on ground water. For a comprehensive treatise on this subject the reader is referred to the work of the Utah State University Foundation (90).

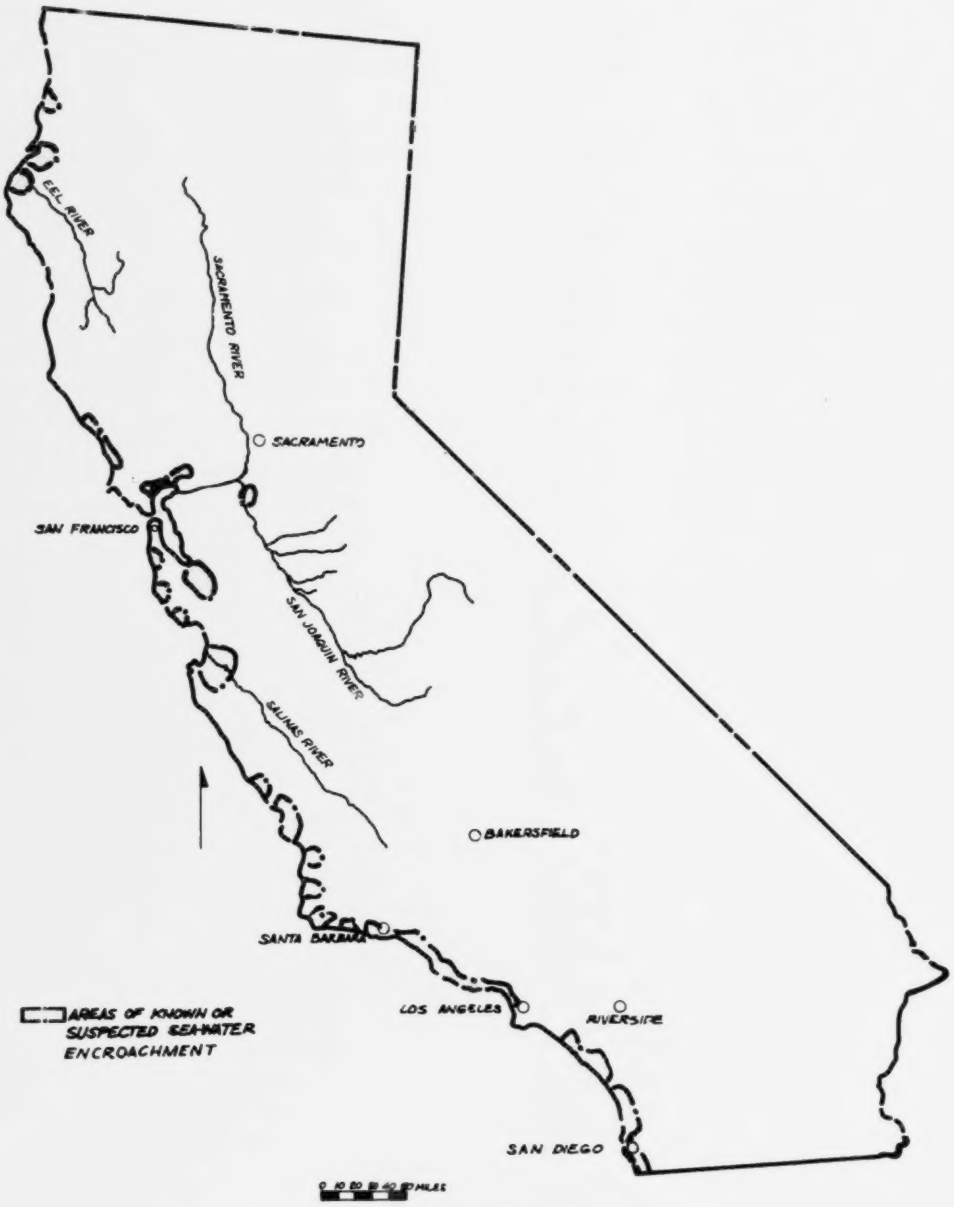
Many engineers and scientists have reported research and observations related to this subject--Scofield (148), Wilcox and Resch (149), Fuhriman (150, Thorne and Peterson (151), Reeve and Fireman (152), Bouwer (153), Israelsen and Hansen (154), Bower et al (155), and others. Undoubtedly a large portion of the minerals pollution found in the ground waters of the project area is caused by irrigation return flow. Degradation of ground water on a broad scale is evident in the drainage waters of the San Joaquin Basin in California where a proposal has been made to construct a fresh water canal from the Sacramento River to bring dilution water to the San Joaquin Basin as a means of diminishing the effect of the degraded drainage water collected in the San Joaquin River (156).

Sea Water Encroachment

In California, there are 262 ground water basins which contain water bearing deposits open to the ocean or to saline inland bays (157). In many of these basins over-development of ground water at a number of locations in California has caused the sea water to encroach into the fresh water areas. These conditions usually have developed in the alluvial plain of various rivers draining into the ocean, especially when intensive development of the ground water supplies has occurred. The Water Resources Council (6) reports that areas of sea water intrusion have developed in the flood plains of the Eel, Mad, and Russian Rivers north of San Francisco; throughout the San Francisco Bay area, in the Salinas River flood plain bordering Monterrey Bay, and in all heavily developed coastal areas along the California Coastline--San Luis Obispo, Santa Barbara, Ventura, Oxnard, Los Angeles, Long Beach, Santa Ana, Oceanside, LaJolla, and San Diego. There have been instances of sea water encroachment into the rich Sacramento Delta, partly from surface streams and partly from ground water. Regulations governing the control of the Sacramento River include the provision that about 4000 second feet of water must flow continuously from the Sacramento River Channel into the upper reaches of San Francisco Bay to assist in repelling the salt water. Extensive studies have been conducted related to the problem of sea water encroachment. The California Department of Water Resources (157) reports that the most serious intrusion has occurred in the following areas (Figure 10).

1. The West Coast Basin of Los Angeles County
2. The East Coastal Plain Pressure Area of Orange County
3. Petaluma Valley in Sonoma County
4. Napa-Sonoma Valley in Napa and Sonoma County
5. Santa Clara Valley in the San Francisco Bay area
6. Pajaro Valley in Monterey and Santa Cruz Counties
7. Salinas Valley area in Monterey County
8. Oxnard Plain Basin in Ventura County
9. Mission Basin in San Diego County

There are detailed studies in a number of the areas of most serious encroachment (158, 159, 160) as well as some laboratory and theoretical analyses of the problem and possible counter-measures (161). Various water using agencies in California have established programs to reverse the movement of sea water encroachment. For example, in the Los Angeles area, three "barriers" have been developed against the sea water encroachment. The barrier is established by injecting non-saline water at a line of injection wells whose axis roughly parallels the ocean source. The theory of the barrier is that by injecting the water, the hydraulic gradient is reversed, so that flow is toward the sea water source instead of away from it. At some locations saline water is also pumped from the seaward side of the barrier to assist in developing the seaward gradient. Alves and Hunt (162) in the 5th Annual Report of the Alamitos Barrier Project, reported the completion of additional injection wells but a landward movement of salt water still existed despite injection of 5530 acre feet of fresh water and extraction of 1823 acre feet of salty water seaward of the barrier. McIlwain, Pitts, and Evans (163) reported on the West Coast Barrier, located near the coast between Torrance and El Segundo for the period 1967-69. Seventy-seven thousand acre feet of filtered Colorado River water was injected in the barrier area. Injection at this barrier began in 1953. Effectiveness varies with depth and location, but generally, the pumpage on the landward side of the barrier has resulted in an increase in the landward gradient. However, chloride ion concentrations at certain points show a decrease and indicate that no intrusion is occurring in the northern half of the Barrier in deeper aquifer. In the southern half of the Barrier, there are evidences of continued intrusion in the deeper (San Pedro) aquifer. There were also signs of over-injection in the shallow sand aquifer. In the intermediate (Silverado) aquifer there were signs of general improvement.


EEL RIVER
SACRAMENTO RIVER
SACRAMENTO
SAN FRANCISCO
SAN JOAQUIN RIVER
SALINAS RIVER
BAKERSFIELD
SANTA BARBARA
LOS ANGELES
RIVERSIDE
SAN DIEGO
AREAS OF KNOWN OR SUSPECTED SEA-WATER ENCROACHMENT
0 10 20 30 40 50 MILES

AREAS OF SEA-WATER ENCROACHMENT ALONG THE CALIFORNIA COAST

FIG. 10

Problems of "clogging" of injection wells are considered to be serious and have required considerable expenditure of funds to "re-develop" the wells--a process similar to development by bailing, cleaning, and surging. The causes and cures of clogging are not definitely known, but it has been learned that filtration of water is usually necessary before injection (164). Bookman and Edmiston (165, 166) report on general problems of management of the ground water in the Los Angeles Area, including the extensive replenishment program.

The third barrier, known as the Dominguez Gap Barrier, has only recently been established to control sea water intrusion in the San Pedro Bay area, between the Alamitos and West Coast Barrier. The Dominguez Gap Barrier was scheduled to begin operation in 1971, and the effect of this barrier is not known at the time of this writing.

In addition to the barrier projects, it should be noted that water has been added to the ground water by "spreading" for many years in California. Michelson (167), reported that spreading began in 1896 on Santiago Creek and in 1900 on the Santa Ana River. Volk (168) reported that up to 1933 a total of $227,000 had been expended on the Santa Ana River spreading ground and that 266,784 acre feet of water had been spread. Land (169) reported on various methods of getting water into the ground, and Freeman (170), Muckel (171), Sonderegger (172), and Hill and Whitman (173) all reported on various practices and operational problems in the water spreading program at various locations in California. These early programs were intended to provide underground storage for water. Only after the over-pumping of more recent times have the "water barrier" methods been used to prevent intrusion of sea water in coastal areas.

In the Salt Lake Valley of Utah, the Great Salt Lake, (with a salt content of over 200,000 mg/l) is underlain by relatively impermeable lakebed deposits. According to Marsell (174) these deposits form an effective barrier against the movement of these highly saline waters into any of the important ground water aquifers. There is some local opinion linking the lake to some of the saline ground water in the valley, but the authors do not believe that this is very likely. The possibility does exist, however, that the hydrostatic pressures from the mountain-fed fresh water aquifers act as a shield to keep the salt waters from entering the fresh water aquifers in appreciable amounts if any aquifer connections to the Great Salt Lake should exist. Ground waters west of the lake are more highly mineralized than those on the east, which are also nearer to the pressurized mountain sources. It may be that these saline waters west of the lake involve encroachment of highly mineralized water from this large inland sea.

Solid Wastes

In the past, solid wastes were disposed of by burning or surface dumping but these procedures have been replaced by sanitary landfill operations. The solid wastes are dumped into an excavated area and then covered over. Normally the wastes are deposited above the groundwater table and precautions are taken to seal off the wastes from the ground water. This procedure generally prevents the leaching of pollutants from the solid wastes and carrying them on into the ground water. However, the potential for pollution is always present.

When water seeps down through a refuse dump, the leaching process often produces an increase in some of the following pollutants or conditions: hardness, total dissolved solids, calcium, magnesium, B.O.D., acidity, alkalinity (175). The gases of CO_2 and CH_4 are also often generated. As the leachates filter into the earth below the waste material they undergo a purification so that if the ground water is far enough away from the waste material, the pollution potential is significantly decreased.

The landfill operations in Arizona are not causing ground water pollution problems of any known significance. Generally the water table is deep and the rainfall is small so the effect of landfills is not a problem in this state. Nevada's situation is very similar to that of Arizona and refuse disposal by landfill is not a recognized problem.

Only 67 of the 712 dumps in California are classified as sanitary landfills while 125 are considered to be modified sanitary landfills. However, these are the larger dumps and they handle 90% of the solid wastes of the state. At 33 dump sites there is direct discharge to surface waters. Eighty-one sites in the state are apparently close to or in contact with the local ground water. There are 207 of the sites with inadequate control of surface drainage (6). It is likely that some of these conditions are resulting in some ground water pollution problems, at least the pollution potential is there.

In California, standards have been set for landfill operations. The standards are simple and easy to work with and so they are listed here:

Classes of Dumps

1. A dump in an area where there can be no leaching either to the surface or to the ground water. This class dump will take any type of refuse including highly toxic materials.

2. A dump where the natural conditions are such that the area can be made to prevent direct runoff to streams or leaching into the ground water. This type of dump can handle all refuse except highly toxic wastes.

3. A dump where the site cannot be protected from either the ground water or the surface water. Refuse in this type of dump is limited to non-toxic, non putrescible materials such as building material wastes, old concrete slabs, asphalt paving debris, and etc.

There are a few areas in California where sanitary landfills are probably a threat to the ground water quality (138). The alluvial sediments of the Sacramento and the San Joaquin Valleys make these areas a little vulnerable to landfills. The extent of the pollution of ground water is not very well known but it is considered to be a potential hazard. Some areas have required some type of seal to separate the waste disposal area from the ground water.

One of the problems of landfills is the generation of the gases CO_2 and CH_4. The gases disperse into the soil and if they get to the ground water, the CO_2 might increase the corrosive ability of the water by increasing its acidity. If the pH of the water is near neutral and calcium or magnesium are present, bicarbonates may be formed to increase the temporary hardness of the water. The CH_4 is light and would normally rise so that it generally will not have any deleterious effect on the ground water. Often chlorides will be leached out of the landfill dumps and carried into the ground water. In California, sanitary landfills are generally not known to be polluting the ground water on a significant scale, although they still pose a pollution potential.

In Utah, most of the solid wastes are being put in landfill dumps. However, there are some areas which have not been very well designed. The dumps for Provo, Salt Lake City, and Logan are in the lowlands where the ground water table is fairly high. These three refuse dumps handle the solid wastes for over 250,000 people. It is likely that at certain times of the year, the ground water is actually near the refuse disposal area. The nearness of the solid wastes to the ground water means that the potential for ground water pollution in these areas is very large. However, no information is available on the influence these dumps are having on the ground water quality in those areas. In other parts of the state, the refuse dumps are generally in areas where the water table is low and the wastes are isolated from the ground water. Many of the areas are still surface dumps that might pose problems of surface water pollution but not ground water pollution.

Disposal of Oil Field Brines and Other Materials

The production of crude oil is always accompanied by waste water production. The waste water produced is usually a highly saline brine. Disposal of the brine is usually handled by one of three methods:

1. Re-injection underground
2. Discharge to the ocean
3. Discharge to a sump for percolation or evaporation

Each of these methods of disposal has a potential for water pollution. In addition to the problem of disposal of brine, there is also a problem with some waste oil mixed with the waste water. Recommended practice includes careful skimming of the waste to remove the oil before disposal of the water.

In disposing of the water by injection, extreme care must be exercised to prevent the brine from getting into a fresh water aquifer. Disposal to the ocean presents little hazard to the ground water supply as long as the disposal pipe is maintained in good order. Disposal from a sump by percolation should only be used if precautions are taken to prevent the percolating brine from entering into the ground water supply. Collins (176) enumerates a number of ways in which oil field practices can cause pollution. In addition to brine and waste oil disposal problems, he cites pollution hazards associated with the common oil field practice of using acid to increase the formation permeability. Aside from the pollution by the acid itself, the practice also often corrodes the casing causing inter-exchange between aquifers.

There is extensive oil and gas production at many locations within the project area. Wherever oil production takes place there is a constant danger of ground water pollution. However, officials in the areas of greatest oil and gas development, (128, 138, 177, 178, 179, 180) indicate that the industry is being inspected and no known problems of ground water pollution exist related to disposal of oil field wastes. The authors believe it is quite possible that undetected ground water pollution is occurring in oil fields within the project area.

Animal Wastes

During the past two decades, the increase in demand for beef and poultry has resulted in a trend for confined feeding of livestock and concentrated production of poultry. The number of cattle on feed for slaughter in 1967 was 11 million head, an increase of 120% in the past 15 years. In the major poultry producing regions, 50% to 80% of the laying hens and most of the broilers are raised in confinement. In California there was an 87% increase in cattle marketings between 1957 and 1963. Virtually all that growth was associated with an increased number of feedlots handling 10,000 head or more. This trend is continuing at the present and is expected to continue in the future (181).

Livestock on American farms produce about 2 billion tons of manure each year. This tremendous production of animal wastes has resulted in a large waste disposal problem. The animal waste problem has already resulted in the pollution of many surface water supplies and it has contaminated some ground water supplies. Studies have shown that the movement of pollutants down through the soil from unpaved feedlots is minimal (182). Nitrates moved the most rapidly through the soil profile. However, these tests were limited in scope and feedlots on a more porous soil might cause serious pollution problems to the ground water below. Barnyards and feedlots have been cited as sources of excessive nitrate-nitrogen in shallow wells in Nebraska and Illinois (181).

Sometimes the animal wastes are spread out on the land as a means of disposal. The amount of waste material that the land can handle without causing a ground water pollution problem has not been determined yet. An estimate has been made that there are about 17.3 billion pounds of nitrogen produced in a year by the farm animals such as hogs, cattle, and chickens. The disposal problem connected with these wastes is a large one and such large waste production produces a high potential for the pollution of the ground water supplies.

Contaminants attenuate to harmless or innocuous levels at certain distances from a waste site by mechanisms of decay, sorption, and dillution (152).

Some agricultural wastes decay or degrade more rapidly than others depending on the presence or absence of oxygen, other wastes, or other materials while other wastes persist indefinitely. The survival of bacteria and viruses is not well known, but the survival of many is thought to be relatively short away from their nourishing environment. In general, biological contaminants decay more rapidly in contact with air.

Some pollutants such as phosphates move slowly or scarcely at all because they are sorbed by or react chemically with the earth materials. Because of ion exchange or some other mechanism, clays tend to retain many contaminants better than do sands.

Dilution is another process which tends to disperse the contaminants. This process is inadequate, however, under many conditions.

Nitrates and biological contamination are in general the most adverse pollutants of animal wastes. Nitrates in excess of 45 mg/l have been known to cause methemoglobinemia in babies (blue babies) and they are often toxic to livestock. Shortly after cattle and sheep drank high nitrate water, 3100 ewes and 300 cows experienced abortions in one operation reported by Wadleigh (183). In one study of the nitrate content in 6000 rural water supplies in Missouri, Smith (184) concluded that infiltrates from feed lots were the main source of nitrates in the ground water.

A review of biological contamination of ground water by Mallman and Mark (185) cites a number of examples in which bacteria and viruses have moved from several inches up to 800 feet. Eliassen and others (186) made calculations to determine the bacterial movement in a large number of soils.

Animal wastes sometimes produce other adverse effects on ground water. These may be caused by organic compounds requiring oxygen for degradation; from materials that cause color, taste, and odor problems; from feed additives, cleaning materials and pest control chemicals which in addition to being pollutants, may affect the attenuation of other materials, from addition of salts; from changes in the pH of the ground water; and from plugging of the aquifer.

ARIZONA

The livestock in Arizona were estimated as 683,000 cattle, 46,000 hogs, and 1,100,000 chickens in 1967. The animal wastes from these sources were estimated to have produced 149,000 tons of B.O.D., 48,500 tons of nitrogen, and 15,000 tons of phosphorous. Most of the livestock in the state are scattered out on the range so only those animals concentrated in feed lots or poultry ranches were considered as potential pollution problems. In 1967 the state had 112 cattle feed lots of the following sizes: 72 lots with 500 to 2,999 animals, 28 lots with 3,000 to 9,999 animals and 12 lots with 10,000 to 50,000 animals. In that same year the poultry ranches were 84 poultry ranches with 50 ranches of 300 to 4,999 chickens, 21 ranches of 5,000 to 29,999 chickens, and 13 ranches of 30,000 to 100,000 chickens. The hog feed lots numbered 32 with 15 lots of 200 to 499 hogs, 8 lots of 500 to 999 hogs and 9 lots of 1,000 to 10,000 hogs (10).

Nationally the major cause of pollution from feed lots is stream runoff from the lots. Because of low annual precipitation in Arizona, the surface runoff is small and the seepage water is also low. The soil removes most of the oxygen demanding wastes and the soluble phosphates are absorbed by the soil. Some of the nitrogen in the form of soluble nitrates might leach down to the ground water. The overall effect will depend principally on the nature and the permeability of the subsoil and the depth to the water table.

Although animal wastes are a potential source of ground water pollution in Arizona, they are not the cause of any known major pollution problems at the present time.

CALIFORNIA

In 1968, the beef cattle plus the dairy cattle numbered almost 1,900,000 head. Although most of the cattle were fed on the open range, there were 453 feed lots in operation. The poultry population was about 260 million and many of those were concentrated in over 4,000 poultry ranches. The hog population was about 150,000 head. The estimated wastes per year resulting from the confined animals totaled the following (6):

Solid Wastes	23,000,000 tons/yr.
BOD	810,000 tons/yr.
Nitrogen	220,000 tons/yr.
Phosphorous	44,000 tons/yr.

Most of these wastes are spread back on the land for agricultural purposes and these wastes seldom cause any pollution problem in the ground water. From this study, it also appears that in the immediate vicinity of the feed lots there are no known ground water pollution problems. It is still true that all feed lots pose a pollution potential and so areas near large feed lots should be monitored occasionally to make sure that the ground water is not being polluted.

NEVADA

In 1965, Nevada had a little over 500,000 head of cattle (8). About 20% of these cattle were being fed in feed lots. The other livestock included 5,000 hogs, 33,000 chickens and 200,000 sheep. The wastes from the feed lots were as follows:

24,000	tons of BOD
8,300	tons of Nitrogen
2,600	tons of phosphorous

Most of the animals were out on the land but these wastes from the feed lots were also put back on the land. There is no indication in Nevada that animal wastes are creating a ground water pollution problem. With the low average rainfall in Nevada of about 9 inches, the ground water pollution potential from animal wastes is not very high.

UTAH

The 1965 livestock population of Utah was estimated at the following figures (12)"

Cattle	800,000
Hogs	40,000
Chickens	1,100,000
Sheep	900,000

The animal wastes from the livestock in confinement average 54,000 tons of BOD, 16,000 tons of nitrogen, and 5,400 tons of phosphorous. In Utah there seem to be a number of places where animal wastes create a surface water pollution problem, but they do not seem to be any more than just a potential pollution threat to the ground water.

In summary, the animal waste problem has not been studied extensively in the area of this present inventory, and so it is not generally recognized as an active source of ground water pollution. Probably less than 20% of the cattle in this area are confined in feed lots, but feed lots are increasing in number and the animal wastes may become a significant source of ground water pollution in the years ahead.

Accidental Spills of Hazardous Materials

Accidental spills of liquid wastes, toxic liquids, gasoline, or oil sometimes pose a serious pollution hazard. Generally the spillages result in surface water or air pollution but occasionally the ground water is affected. One such occurrence (cited in Section V), was first noticed in southern California in September of 1968 (130). Gasoline was noticed in a water well near the city of Glendale. The source of the gasoline was unknown but an oil company transmission line was suspected. The pipeline and many gasoline storage tanks were carefully tested and all were reported tight except for a few very minor leaks in the tanks which were repaired. These small leaks were not the source of the gasoline pollution which was quite wide spread. No leaks were found in the area where the main problem existed but a leak was found in a gasoline transmission line about 2 miles from the polluted area. This line was drained and removed from service, but the main source of pollution was not clearly determined. About 30 wells for observation, containment, and removal were drilled around the problem area and the polluted water was pumped out. There were two principal removal sites and two plants were set up to separate the gasoline from the water. By April, 1970, the gasoline in the water at the two removal sites had dropped to almost nothing. Efforts to contain the pollution and extract it as rapidly as possible continued. Monitoring of the area seemed to indicate that the main problem of the spill had been controlled.

This spill of gasoline into the ground water in southern California was an unusual example of a source of ground water pollution. However, when accidents of this nature do happen, the results can often be very damaging. The Water Quality Act of 1970 required the establishment of a national contingency plan for the accidental spills of hazardous materials. The national plan also calls for regional plans which have not yet been completed. Warning and monitoring systems should be established and methods should be researched for containing and cleaning up accidental spills of hazardous materials.

Water From Fault Zones and Volcanic Origin

Most ground water which emerges as mineralized springs is deep-seated water as opposed to "shallow" ground water moving through materials closer to the earth's surface under ordinary hydrostatic pressures. Deep-seated waters have a complex origin, that is, they may include water derived by absorption from the land surface, water trapped in sedimentary rocks at the time of their origin, and water expelled from igneous rocks during crystallization. Milligan, Marsell, and Bagley (187) state the following in relation to the origin of these waters:

> "It is believed that the movement of these deep-seated waters is not due to hydrostatic head, or in other words, these waters are not connected with overlying and connecting bodies of water. The flow of these deep-seated waters is believed due to thermal and pressure gradients operative deep within the earth. A spring with

> constant flow not subject to seasonal changes and with a high temperature probably has a deep-seated origin. Further evidence as to the deep-seated origin of mineralized spring water is the presence of important faults or other structures along which water could rise."

These deep-seated waters usually come forth as fault springs, volcanic springs or fissure springs. Most of the mineral and thermal springs of the project area originate from deep-seated waters.

Throughout the study area there are many mineral springs. Many of them may also be classed as thermal springs since the temperature of the water is higher than the normal ground water of the area. In fact, most of the significant mineral springs of southwestern U.S. are of the "thermal" category. Milligan, Marsell and Bagley (187) made a detailed study of mineralized springs in Utah. They determined that almost all of the mineralized springs in Utah have elevated temperatures and also are closely associated with zones of geologic faulting. Mundorff (188) in studies of thermal springs in Utah, arrived basically at the same conclusion. In Arizona, Feth (189, 190) reports on a number of mineral springs which originate in the Mogollon Rim in Central and East Central Arizona. These springs discharge large quantities of dissolved minerals into the Salt River continuously.

Waring (191) and Stearns, Stearns, and Waring (192) have reported on thermal springs in the U.S., and also in other parts of the world. They indicate that most thermal springs also contain a high concentration of minerals. Waring (191) reports over 200 thermal springs in California, about 200 in Nevada, 65 in Utah and 21 in Arizona. The majority of them are associated with geologic fault zones or volcanic origins. In a limited number of locations the waters are of surface origin having been heated by a volcanic source but not originating there. White (193) reported on studies relating thermal springs and volcanic activity. A discussion of the occurrence of thermal and mineral springs at various locations in the project area is presented in the following paragraphs:

ARIZONA

The central and southern parts of the state of Arizona are occupied by mountains composed of Crystalline rocks and folded and faulted ancient marine strata. In many areas these older rocks are covered by Tertiary volcanics which provides a source of heat for a number of the thermal springs of the state. The faulting along the Mogollon Rim has also provided an escape route for much underground water along the fault surface as has already been mentioned. Three main springs in this area, flowing 900 to 1100 gallons per minute each, deposit over 200 tons of dissolved solids into the Salt River daily. In the Grand Canyon of the Colorado, the Lava Warm spring erupts near Lava Falls

Rapids. In this area there is a spring flow of 6700 gallons per minute. Akers (194) reports on water from fault zones in the Flagstaff area.

CALIFORNIA

The volcanic activity in California has been responsible for many thermal springs. Mt. Shasta is the most prominent of the lava masses. In the extreme northeastern part of the state near Lake City, White (195) reported on violent mud-volcano eruptions at Lake City Hot Springs. The Clear Lake basin in the coastal mountains northeast of San Francisco contains many hot springs, including "The Geysers" and others. Many of the springs in this area contain high sulfur content (196, 197) and in some springs a considerable amount of nitrate is found (198). In northeastern part of the state, a number of springs rise from fault zones in Surprise Valley. Further south in Honey Lake Valley, springs with temperatures near the boiling point are found. Along the Sierra Nevada range of mountains considerable faulting has occurred in southern portions in the granite or gneiss formations and a number of springs issue forth there. In the Coastal Range, in addition to "The Geysers" already mentioned, there are a number of warm mineralized springs originating in fault zones or from volcanic rocks. A number of extremely warm springs issue forth from the San Bernardino and San Jacinto mountains, especially in the areas of geologic faulting which is extensive.

Probably the most famous fault in California is the San Andreas Fault which extends from Tomales Bay, north of San Francisco, more than 600 miles southward into the Salton Sea basin. No well-known thermal springs issue forth, but it does include a number of mineral springs which are of local importance. The same is true for the California desert area, but a number of resorts use water from mineral thermal springs--both in the desert and other areas of the state.

In terms of total flow, the Paso de Robles thermal spring is the largest in the state, with a flow of 1700 gallons per minute and a temperature of 105°F.

NEVADA

Most of Nevada is a region of detached mountains separated by desert valleys. Many of the mountains are composed of granite and ancient metamorphic and sedimentary rock; others are composed chiefly of lava. The structure includes much complex folding, but in many places it is dominated by block faulting. Thermal mineralized springs are scattered throughout the state and most are closely related to faults. In northeastern Nevada, several hot springs issue from limestone and shale mountain areas. Near the northwest border, a number of springs issue from intrusive granite. Numerous warm and hot springs rise from lava hills along the western side of Black Rock Desert west of Winnemucca and also further south in the area of Pyramid Lake.

The valley of the Humboldt River east of Winnemucca is bordered by hills of lava which yield a number of mineralized warm springs. South of the Humboldt River Valley a number of boiling springs issue from faulted strata. These springs deposit considerable calcium carbonate. Boiling springs also issue from several lava areas south of this valley.

A few miles southeast of Reno, the Steamboat Springs rise with water near boiling temperature which contains high concentrations of silica and sulfide minerals. In the central part of Nevada, the Big Smoky contains many hot springs, and similar conditions exist in Diamond, Steptoe and White Pine Valleys nearby. In southern Nevada several wide flat valleys contain warm mineral springs under artesian pressure.

UTAH

Most of the mineral and thermal springs of Utah occur in the fault zones along the Wasatch mountain range, extending north and south throughout the whole of the state. A number occur in the Great Salt Lake Desert lands of western Utah--Locomotive Springs along the Hansel Valley fault in northwestern Utah, Promontory Point Hot Spring on the east side of Promontory Point, Blue Spring near Howell, Grantsville Warm Springs near Grantsville, Big Spring near Timpie at the northwestern tip of the Stansbury mountains, Deseret Springs in Skull Valley, Fish Springs near Callao, and the Gandy Warm Spring near Gandy.

The mineralized springs in Utah have a pronounced effect in degeneration of the quality of surface streams at a number of locations throughout the state.

Evapo-Transpiration of Native Vegetation

In the preceding paragraphs the effect of irrigation on the pollution of ground water has been discussed. The process by which the water remaining in the soil increases in mineralization is exactly the same for native vegetation as for irrigated crops. Only the source of the water applied is different, since with native vegetation the source must be either soil moisture applied as rainfall, or the ground water. Use of direct rainfall by vegetation does not have an appreciable adverse effect on ground water quality because the rain water is of good quality. On the other hand, ground water containing dissolved minerals is subjected to a concentrating action as the vegetation utilizes some of the water leaving the salt behind in solution. For many types of vegetation the effect is minimal, but in the case of water-loving vegetation called phreatophytes, the gross effect on the loss of the water resource and on the increase in the mineral content of the ground water is very great. In several parts of the project area, large areas of the native phreatophytes are considered to be a serious problem.

Fletcher and Elmendorf (199) estimate a total area of eleven million acres of phreatophytes in the fourteen western states with the following estimates for the four states of this report:

State	Area of Phreatophytes (Acres)	Annual Water Use (Acre-feet)
Arizona	405,000	1,280,000
California	317,000	1,150,000
Nevada	2,801,000	1,500,000
Utah	1,200,000	1,500,000
TOTAL	4,723,000	5,430,000

Detailed investigations have been conducted on the characteristics of phreatophytes. Robinson (200) discussed 74 different species in detail. Studies of the water using characteristics and water quality effects of phreatophytes have been reported by Robinson (201, 202), by Muckel and Blaney (203, 204), by Shamberger (205), by Gatewood and others (206), by Lewis (207, 208) by Bowie and Kam (209), Hendricks and others (210) and by Turner and Skibitzke (211). These reports include work in all of the project area. All of these reports emphasize the fact that the phreatophyte effect upon ground water quality is considerable.

Injection Wells for Waste Disposal

Injection wells are sometimes used in connection with ground water replenishment programs and have already been discussed in an earlier sub-section. In the oil industry, brines are often re-injected underground as a means of disposal and also as a secondary oil recovery operation. This has also been discussed in a previous sub-section. Occasionally, industries or others have used shallow injection wells to dispose of liquid wastes. For example, Follett (94) reported that various electronic industries near Phoenix and Tucson, Arizona, have in the past, disposed of metal plating wastes by injection wells. Follett reported that heavy metals, primarily chromium, showed up in the ground waters of the areas involved but this method of waste disposal has now been stopped. Deep injection wells have been considered for disposal of radio-active wastes (212, 213). An analysis of relative cost of disposal by injection for municipal wastes, failed to consider the pollutional aspects of such practices (214).

In 1967, it was estimated (215) that there were 40,000 salt brine disposal wells in U.S. and 110 injection wells to dispose of other wastes. The number in the project area is not known. Smith (216) stated that most disposal wells are successful and that only a few give the method a bad name. Sheldrick (217) indicated that earthquakes in the Denver area were likely caused by injection at the Rocky Mountain Arsenal. Piper (218) pointed to the need for better information and better controls on injection. He also indicated that the maintenance of a given pressure condition is simplified if wastes withdrawn (such as brines in oil well development) are re-injected into the same aquifer. On the other hand, many of the deep aquifers contain large volumes of gas which can be compressed; and under these conditions, injection of large volumes of liquid does not cause a serious problem from a volume of pressures standpoint. Wesner and Baier (219) discussed injection of reclaimed wastewater underground. It is the belief of the writers that deep-well injection involves many potential pollution hazards. It is not possible to generalize in a discussion of problems related to deep-well injection because of the great variation in geologic conditions at various locations.

Fertilization of Agricultural Lands

The problem of irrigation return flow in water quality control and the need to maintain a "salt balance" in arid region soils has already been discussed. The principles which are operative in relation to the salt balance also impose another water pollution potential on the agricultural operation. As fertilizers and water are applied to the soil, part of the fertilizer will be leached on through the soil in the drainage water. This is especially true of nitrates. Pratt (129), Doneen (132, 133) and Jopling (220) all indicate that part of the nitrates in solution in irrigation water are carried on through the rooting zone of the plants into the drainage channel or the ground water. Phosphate fertilizers do not become a problem in this regard because they are adsorbed on the soil particles and become "tied up" in the soil. Stout and others (108) traced the movement of nitrogenous matter from the ground surface to the water table. Robbins and Kriz (221) discussed the general problem of fertilizers in causing ground water pollution. They report a number of research reports which point out the potential hazard of over-fertilization in ground water pollution. However, they point out that the extent of fertilizer use will likely increase in the U.S. in the future. It should be pointed out that the plants use a part of the nitrogen in solution, but a portion usually remains with the percolating water to become a ground water pollutant. Nitrogen is the only fertilizer element that has been found to be a problem related to ground water pollution. This is a potential problem throughout the study area but has only been identified as an actual source of pollution in a few areas. It certainly is the cause of nitrate pollution of ground waters at some locations and is likely an important factor in many others. As noted in the previous chapter, there are many locations in the study area where nitrates are dangerously high. Fertilizers undoubtedly contribute to the hazard in many of them.

Land Disposal of Wastes-Municipal and Industrial

Land disposal of wastes is practiced at many locations throughout the U.S. Since agricultural wastes are being discussed in other sections of this report, this section deals only with the land disposal of municipal and industrial wastes.

MUNICIPAL WASTES

There are a number of municipalities which dispose of sewage wastes by spreading on the land. If this practice is controlled carefully and if a large enough area is used for disposal, it is not likely to cause ground water pollution. Undoubtedly there are many locations where this is done in a safe and satisfactory manner. It is also likely that there are a number of examples of this method of disposal where pollution caused by this method of disposal has gone undetected. In the course of the investigation leading to this report, ground water pollution problems in the vicinity of a number of municipal sewage treatment facilities suggest this as a source of pollution.

At Tucson, Arizona, a project to reclaim waste water involves land spreading of sewage for irrigation purposes (24). In the early stages of this project, considerable nitrate was getting into the ground water. At Phoenix, Arizona, Bouwer (222, 223, 224) reported on the results of research on land spreading of municipal sewage plant effluent. His results indicate limited travel of the various pollution parameters. McMichael and McKee (225) reported on similar studies in the Los Angeles area at Whittier Narrows. Their work was oriented toward the degree of treatment of municipal sewage effluent prior to its application to water spreading grounds used to replenish the ground water supplies. Surface disposal of sewage effluent in the Fresno metropolitan area is reported to have degraded the quality of ground water in the area of the sewage treatment plant (134). In San Bernardino and Riverside Counties of California, studies were reported in 1965 (226) relating to the dispersion and persistence of synthetic detergents in ground water--again relating to the spreading of sewage effluent for the replenishment of ground water supplies.

INDUSTRIAL WASTES

Land disposal is a common method of handling of many industrial wastes. Throughout the four states of this study, there are many locations where industrial wastes are disposed of in this manner. As is the case with many waste disposal practices, pollution may occur and yet remain undetected. One example of industrial waste land disposal becoming a problem has been reported in the vicinity of Hollister, California, in the Pajaro River Basin (99). Two canneries disposed of wastes from their canning operation in stream terrace deposits and alluvium. In addition to food products residue, their waste water also contained caustic soda used as a peeler for apricots and tomatoes. Most of their waste water reached the ground water body.

Seepage of Polluted Surface Waters

In many instances, careless practices related to control of wastes result in surface streams becoming polluted. Often this water finds its way into the ground water. Several examples of this type of pollution have been observed in the study area.

In the Vernon district of the Los Angeles metropolitan area, ground water pollution from industrial waste discharge into Compton Creek was reported by Zielbauer (227) in 1947. High concentrations of total dissolved solids as well as sulfates, chlorides and phenols were reported.

In the area of Barstow, California, the Mojave River channel is a dry bed most of the time--except during infrequent periods of storm runoff. Both municipal and industrial waste disposal into the river channel created a serious ground water pollution problem. A series of reports in 1960 (228), 1966 (229) and 1970 (143) indicate that phenols, detergents, chrome, and MBAS (methylene Blue Active Substances) were present in nearby wells. Objectionable tastes and odors were also found in the area ground water, variously characterized as "chemical", "medicinal", "sulfide", "musty" and sewage". The study in 1960 indicated that phenol and chrome wastes came from the railroad shops, resulting from large quantities of diesel oil (24,000 gallons per month) and cooling system drainage (containing hexavalent chrome as a corrosion inhibitor) being wasted to the river channel. A large part of the detergent was believed to have come from the railroad laundry, which had operated between 1949 and 1959 when it was closed by the company. Most of the sewage was believed to have come from the Barstow City sewage plant which was re-designed and rebuilt in 1953 and again in 1968. The railroad company domestic sewage was treated separately until 1968 when it was included in the city plant. The underground flow in the Mojave River Basin was estimated by the U.S. Geological Survey (230, 231) at about one million gallons per day. The California Department of Public Health estimated the velocity at one mile in five years (229). One surprising result of the studies in the Barstow related to the persistence and spreading of the degenerated water after extensive corrective measures were taken.

Both the railroad company and the City made extensive improvements to eliminate the sources of pollution between 1960 and 1970, yet the 1970 report (143) indicated additional expansion of the degraded water and its advancement to wells where it had not appeared previously.

Urban Runoff

Urban storm water disposal is often accomplished by spreading in areas of high infiltrations. Abandoned gravel pits and old stream channels are examples of areas utilized for this purpose. This practice is often encouraged in arid regions as a means of replenishment of the ground water supply. These practices are used at many locations throughout the project area, and they represent a potential ground water pollution hazard. No specific reported instances of pollution of ground water by this means are available to us, but the potential certainly exists.

It is common practice in areas of freezing weather to scatter salt on icy roads to melt ice and snow as a traffic safety measure. In urban areas, the runoff from this melting ice and snow is collected in the storm sewer and conducted to some disposal location. Often the disposal is underground. The resultant increase in total dissolved solids in the ground water may be a problem. This is particularly true in arid regions, where dissolved minerals in many waters are already near the critical level.

Considerable urban development is occurring in mountain areas away from the traditional urban areas. Sewage disposal in these areas is often into septic tanks, with a resultant detrimental effect on ground water quality areas. No actual measurements of such pollution are available to us, but a number of such areas are known to exist at several locations in the project area. These areas should not be confused with recreational home developments which are used only seasonally.

Connate Water Withdrawal

Brines are often found in the sedimentary deposits of the earth's crust. Many brine deposits are connate--that is, water trapped in the sediments as they were being deposited. They often occur in places where no oil or gas fields are present. The entrapment of the brine may in some instances have been brought about by an overlying body of water or a water bearing aquifer with interconnections to the aquifer containing the brine. As the less saline water is pumped from the overlying aquifer, the salty brines may be withdrawn in much the same manner as sea water intrudes into a fresh water aquifer. Such withdrawal is always the result of over-pumping of the existing water supply.

In the study area, there are no known locations of connate water withdrawal except in connection with oil well development, which will be discussed in the next section of this chapter. However, the potential for such withdrawal is present wherever brine deposits underlie the better quality waters. Some connate water withdrawal has been indicated by high salinity in some heavily-pumped wells of the San Joaquin Valley (138).

Mining Activities

Most mining activities encounter ground water, and disposal of the drainage water from the mine workings is often one of the troublesome problems of the whole operation. Ordinary excavation procedures do not usually have any direct adverse effect on the quality of the drainage water except for the causing of some turbidity. However, in coal mine workings, the mining usually exposes pyritic material which, upon contact with percolating water and the oxygen in the mine shaft, forms sulfuric acid. However, in most arid regions, the soils and natural waters are alkaline; and thus tend to neutralize the acid. For this reason, acid mine drainage is not as serious a problem in the project area as it would be in other parts of the country. No indication of any problem has been given by any federal, state or local officials in any of the states of the study area.

Drainage of waters from copper deposits often contain considerable metallic copper, and ground waters in the vicinity of copper deposits such as occur in Arizona and Utah should be carefully checked if this is a potential problem. However, drainage waters are often "processed" to salvage the copper present.

Many natural minerals which can cause serious ground water pollution occur in the project area. One would naturally expect that ground water in the vicinity of these natural deposits could be contaminated.

Aquifer Interchange

The exchange of ground water from one aquifer to another represents an important potential source of ground water pollution. It is known that quality of ground water varies considerably from one aquifer to another. One aquifer may contain a source of pollution which another does not. Common well drilling practices may permit the movement of water from a polluted aquifer into another which is relatively free os pollution. There may be aquifer connections at springs or geologic fault zones. Measured information is not available to indicate the degree to which an interchange of water between aquifers actually occurs, and it is not possible to state locations at which such a problem may occur. Investigations in the San Joaquin Valley of California (232) indicate the possibility of interchange between aquifers since wells drilled through shallow brackishwaters are frequently gravel-packed and perforated in all water producing zones. It should be recognized as a potential problem that could exist in the project area.

Mineralization From Soluble Aquifers

The effect on ground water quality of flow of water through aquifers containing soluble minerals is difficult to measure. Nevertheless, it is a significant factor in the quality of ground water. In Nevada and

Utah many of the ground water basins are closed basins with alluvial fill in the valley. The natural recharge water flows from the outer edges of the valley toward the center of the valley and in the process minerals are dissolved into the ground water. Therefore, the ground water near the center of the closed valleys generally has a high content of total dissolved solids. Normally, impermeable rocks exist between basins so most ground water reservoirs consist of the internal drainage within the basin. Under these conditions, the quality of the ground water is good near the recharge areas at the edge of the valley and becomes progressively poorer quality toward the center of the closed valley. Evaporation of accumulated surface water at the low point in the closed basin results in the accumulation of salts at the surface and these salts are often carried to the ground water reservoir by recharge water seeping from the surface to the ground water reservoir. This process also tends to pollute the ground water near the center of the valley more severely than at the valley edges.

Since the best quality ground water is around the periphery of a closed valley, most of the wells for developing the use of the ground water, are drilled near the outer edges of the valleys. If the water pumped per year is more than the natural recharge, the ground water table begins to go down. If this trend continues, the water table at the edge of the valley is lower than at the center of the valley and there is a reversal of the flow of the ground water. The water toward the center of the valley begins to flow toward the outer edge of the valley. Since the water from the central part of the valley is generally more highly mineralized than the water in the natural recharge area, the quality of the water in the well begins to decrease. Therefore, development of the ground water use is the cause in some areas of a deterioration of the ground water quality. A number of investigators have found a general degradation of water as it moves through an aquifer in a direction away from the point of recharge. In the Santa Ana area (128), and the San Joaquin area (138) of California and in a number of other regions of the project area, the ground water has been shown to become degraded as the water moves through the ground water aquifers.

Crop Residues and Dead Animals

Crop residues include that portion of the plant that is left in the processing shed after the harvest. For every pound of food that gets to the store to be sold, between 2 and 5 pounds of residues are left in the field and the packing shed. In a few specific cases, crop residues might become a ground water pollution problem. In general, however, crop residues are not a pollutant to the ground water. In fact, residues are not generally a very serious pollutant to agricultural waste waters (233).

Dead animals do not ordinarily have any serious effect on ground water quality. Larger farm animals are usually disposed of by the rendering and animal by-products processor. The dead sheep or wildlife on the range are usually disposed of quickly by other forms of wildlife. According to Hart (233) and Robbins and Kriz (221) the disposal of dead poultry is often done in such a manner that it creates a serious ground water pollution hazard.

Poultry producers are handling ever-increasing numbers of fowl in their operations. Flocks of 100,000 are common. A loss of one per cent per month from a 100,000 fowl flock will average 35 dead fowl per day. Many producers dispose of the dead birds by burial in a large trench or in a septic tank. With percolating waters in the vicinity of such a mass of decaying organic matter, the pollution potential is considerable. No actual reported instance of such pollution in the project area is known, but there are many poultry producers in the area so the potential does exist.

Pesticide Residues

The term "Pesticide" covers any material used to control, destroy or mitigate pests; and includes insecticides, herbicides, fungicides, nematocides, rodenticides, bactericides, growth regulators and defoliants. Whenever these materials may be found in the ground water, the consequences can be serious. Robbins and Kriz (221) point out that there is insufficient information available on many facets of the problem. For example, the movement of various pesticides from the surface of the land through the soil to the ground water cannot be verified in many cases. More information is needed to know which of the various pesticides may be degraded by interaction with the soil.

The fate of pesticides once they have entered waste waters is a subject of much speculation. According to Westlake (234), many disappear quite rapidly--through adsorption by plants, adsorption on clay particles, chemical decomposition, and action of micro-organisms. Organophosphorus compounds, as a rule are relatively short-lived in water courses or soils. Organochlorine compounds may persist for long periods of time in water sources, but often are not moved through the soil, but are decomposed in the soil.

Scalf and his colleagues (235) studied movement of DDT and nitrates in a ground water recharge experiment in Texas and found that the nitrates moved readily with the recharge water but that essentially all of the DDT was adsorbed on the sand particles of the aquifer. The solubility of the pesticide seems to have a significant effect upon the movement through the soil. In studies in the San Joaquin Valley (236) using Lindane and DDT the investigators found that the pesticide DDT being of low solubility did not move through the soil into the ground water in significant amounts, whereas Lindane, of higher solubility did move into the ground water in significant amounts. They also pointed out that more chlorinated hydrocarbons are removed through decomposition in the soil than through leaching.

Pollution by pesticides must be listed as an important potential hazard throughout the project area. However, in all of the literature studied and the many interviews conducted in compiling data for this report, no evidence was reported of any measured pollution from pesticides.

Land Subsidence Effects on Water Quality

In a previous section we referred briefly to a problem of arsenic pollution of ground water in the San Joaquin Valley of California. Lofgren (137) has expressed the opinion that the arsenic may have been the result of land subsidence, which is extensive in the area where arsenic is found. His theory is that the arsenic has adhered to clay particles, and as the pressure is increased in the soil due to the subsidence of the land, the arsenic goes into solution. There is a considerable area in California subject to land subsidence, but no other relationship between subsidence and water quality has been suggested at any other location. Miller, Green and Davis (237) report subsidence in excess of 20 feet at some locations in western San Joaquin Valley of California.

Other Causes

SEWER LEAKAGE

Many sewer systems are constructed with poor joints with the result that leakage from the sewer may result in areas where the sewer line is above the ground water table. This represents a potential threat of contamination of ground water. Recent pipe laying practices often require the use of rubber gaskets at the joints with a greatly diminished pollution potential.

THERMAL POLLUTION

It is well known that ground water temperatures at some locations in the country have increased with time. Many industries dispose of heated wastes to the ground water. No specific instances of such thermal pollution problems are known in the project area, but undoubtedly there are some locations where this problem exists. A rise in ground water temperature can have a serious detrimental effect on many users.

RADIOACTIVITY

In the Milling process of uranium ore, there are tailings left which might have a pollution potential for radioactivity of local ground water. Although there are no reported problems from this potential source, uranium ore has been mined rather extensively in Utah and surrounding states, and there might be areas where the ground water has been polluted. There are also other mining operations which result in tailing piles that have some radio-active materials. Although they are not known to be an active source of ground water pollution, they would appear to be a possible source.

Natural radioactivity occurs to some extent in all ground water, as a result of decay products of uranium, thorium, or radium which occur in natural formations. No instances of a detrimental amount of radioactivity are known to exist in the project area.

RECREATIONAL ACTIVITY

The project area includes large areas of public and private land which are used much of the time for recreational purposes. There has been a great increase in recreational use of lands in recent years. Camping, hiking, motorcycling, horseback riding, fishing, boating, skiing, snowmobiling, and hunting are all examples of recreational uses of land and water within the project area. These uses have had a great impact upon the surface water quality and to a lesser degree upon ground water quality. Use of this type will likely increase greatly in the future and the net effect on ground water quality may be considerable.

SECTION VII

RESEARCH AND OTHER NEEDS

There is a vast amount of written material bearing on the subject of the ground water supply and the pollution thereof. The many references in the bibliography of this report attest to that fact. On the other hand, almost no research has been devoted to the solution of the problems related to ground water pollution.

It will be noted that many of the "research needs" listed involve investigative evaluations or studies of an applied nature. The authors believe that there is a great need to bridge the gap between fundamental or basic knowledge and the practical application of knowledge to every day problems. This is especially true in the field of ground water pollution, where the variables are many, and where the greatest promise for useful research appears to lie in the "applied" area.

Determination of Ground Water Development Potential

It is the belief of the authors that many ground water quality problems are inseparably connected to water quantity problems. Overdevelopment of a given ground water aquifer often results in a deterioration of the water quality--sometimes dramatically as is the case when sea water or connate brine comes into an over-developed well. There is surprisingly little quantitative information available which will enable the water resources engineer to define the quantitative limits of ground water development. There are few locations where these limits have been defined. They are sorely needed by engineers and water administrative officials wherever ground water is used. McGuinness (15) made a great contribution in summarizing the best estimates available of ground water development potentials. His estimates were based on geologic and other limited information with no claim to accuracy sufficient to define development limits. He stated "Existing knowledge is grossly inadequate to form a basis for effective development and management of the ground water reservoirs." Techniques for evaluation of pumping and recovery data are available, which will permit determination of the quantity of available ground water supplies. This should be done for all ground water basins where appreciable development exists or is contemplated.

Research on Ground Water Pollution Identification

This report is based upon a thorough review of the literature and personal interviews with various officials having knowledge of ground water pollution problems existing in the study area. Through these sources, many ground water pollution problems have been identified and reported. We believe that this identification is a necessary first step in solving ground water pollution problems. It is our conviction that similar reports should be prepared for other parts of the country. Aside from the inventory value, such reports can serve as a basis for research projects to attack the problems of ground water pollution in the respective areas of the country. We recommend that such studies be conducted throughout the United States.

Research and Investigation on Specific Pollution Problems

In the previous section, the existing ground water pollution problems were listed and classified according to the various causes of pollution. Listed below are recommended research ideas aimed at solutions of some of the problems listed. The list is not intended to be all-inclusive, but to serve as a guide for research which the authors feel can be productive in solving ground water pollution problems in the states of Arizona, California, Nevada, and Utah. The suggestions are classified according to the "causes" listed in the previous section and are presented in the same order as previously. No attempt has been made to establish priorities of suggested research, since great differences exist in the magnitude of the problem. Availability of funds and research capability must have a great influence on the kind, amount and rate of any research undertaken.

NATURAL LEACHING

Since this is a natural process, it is the result of many long term, complex interactions between water and the earth mantle. Improvement programs must either protect the water nearer the source, short circuit the natural processes, or de-mineralize the water. The following research ideas are suggested:

1. In areas of extremely short supply of water, study the feasibility of demineralization of part of a given water supply so that demineralized water may be mixed with raw water to obtain acceptable water.

2. At locations where surface water supplies are available and where satisfactory geologic conditions exist, investigate the feasibility of water spreading in re-charge areas to dilute natural mineralization as well as increasing ground water supplies.

3. Study long term records of salinity in ground water to investigate changes in natural salinity with time. These studies would answer such questions as "Does a long-term leaching process decrease the minerals in the leaching areas, thus diminishing the mineral content increase in total quantity and/or in percentage in years of high water supply?"

IRRIGATION RETURN FLOW

The Utah State Research Foundation, in their comprehensive report previously cited (90), made many excellent recommendations for research on the subject of irrigation return flow. The authors generally concur in their recommendations, many of which relate to ground water pollution. The following suggested research topics include a number of ideas from their report:

1. Conduct studies under a variety of soil mineralization and irrigation water quality conditions to determine inter-relationships between salt balance, efficiency of irrigation, and mineral changes in water as it moves into and through the soil.

2. Conduct investigations to evaluate in large scale irrigation projects, the increases in salinity of irrigation return flow in order to develop techniques for the prediction of such mineralization increases in new irrigation projects.

3. Conduct basic studies of the precipitation and exchange reactions which occur as water moves through mineralized soil.

4. Conduct basic studies related to adsorption of phosphates, heavy metals, and various agricultural chemicals which may be carried into the soil with irrigation water.

5. Investigation of effects of temperature of irrigation water on the pollutional aspects of the resulting return flow and its effect on the ground water.

SEA WATER ENCROACHMENT

Most of the work which has been done to fight sea water encroachment has been of an emergency nature--with procedures and practices being developed in the field to control pollution already existent. The following are suggested research ideas:

1. Evaluate the effectiveness and efficiency of existing fresh water "barriers" established near the California coast to prevent salt water encroachment from the ocean. Do present barriers use more fresh water than necessary?

2. Study ocean-bordering aquifers to determine storage and useable available water so that over-development can be avoided before salt water encroaches into the fresh water aquifers.

3. In areas where geologic conditions are favorable, investigate the feasibility of utilizing a physical barrier such as a grout curtain to prevent encroachment.

4. Investigate mineralization and geologic conditions near highly-mineralized inland seas such as the Great Salt Lake in Utah and Mono Lake or the Salton Sea in California to determine whether the lake water is polluting the ground water.

SOLID WASTES

Disposal of solid wastes is a problem throughout the U.S. The development of methods and techniques for handling the large volume of solid wastes will require ingenuity and wisdom. Ground water pollution is only a small part of the problem. Legislation and regulatory control are needed in all states. This is especially true in relation to toxic wastes and containers used for highly concentrated materials which may be toxic. The following are suggested research ideas:

1. Evaluation of ground water pollution resulting from various kinds of solid waste disposal areas.
2. Development of special techniques for handling highly toxic waste materials to prevent ground water pollution.
3. Development of uniform requirements for management and operation of solid waste disposal areas.

DISPOSAL OF OIL FIELD BRINES AND OTHER MATERIALS

There is a great ground water pollution hazard in the disposal of brines and other waste materials in the oil and gas fields. Rigid inspection and control of disposal techniques is essential on a uniform basis. New legislation will probably be required to insure the kind of control necessary to protect the ground water resources. It is recommended that costs of inspection and control be assessed as a cost against the drilling operation. Suggested research ideas are as follows:

1. Conduct detailed geologic and geophysical investigation in existing and potential oil and gas fields to evaluate potential disposal hazards by re-injection or other methods.

2. Develop inspection procedures which will insure absolute control of ground water quality in drill fields.

3. Investigate the ground water pollution hazards in the use of acids to increase aquifer permeability, including the fate of the acid and possible aquifer interconnections brought about by acid corrosion of the well casing.

ANIMAL WASTE

The concentration of large numbers of animals in a small space has been a recent development in the beef, pork and poultry industries. Pollution of ground water caused by animal waste has been discussed in previous sections. There is considerable reason for concern over ground water pollution related to animal waste disposal. There is a need for design standards and management procedures to guide the industry and the regulatory agencies. Research ideas are as follows:

1. Investigate the effect of various feed lot and poultry management practices on ground water quality. Investigations should include various site conditions and various methods of handling the waste, such as spreading on the land, treatment by aeration or other means, incineration, etc.

2. Develop guide lines for the construction, operation and management of feed lots in order to help solve the animal waste problems and protect ground water quality.

3. Assist the states in preparation, adoption and enforcement of standards to protect ground water quality.

4. Evaluate management practices, related to scheduled inundation of disposal of high-nitrate effluent as reported by Bouwer (223).

5. Investigate the effects on ground water pollution of land disposal by the spreading of large amounts of decomposable organic material on the land surface. Studies should include the movement through the soil of such substances as phosphates, nitrogenous compounds and pesticides and the survival and movement of viruses, pathogenic bacteria, nematodes and other such organisms.

ACCIDENTAL SPILLS OF HAZARDOUS MATERIALS

Accidental spills of hazardous materials represent a constant threat to ground water quality. There is urgent need for the development of detection and control procedures as well as a "diaster" plan to be followed in the event of such accidental spills. New legislation may be needed to implement such procedures. Prevention, detection and correction measures are needed and therefore, applied research should be directed at developing these measures.

WATER FROM FAULT ZONES AND VOLCANIC ORIGINS

In the project area there are many thermal and mineralized springs which represent important sources of pollution at particular locations. Although these sources are of natural origin, some research will be helpful in solving the problems:

1. Investigate the geology of the polluting springs to determine direction of water flow, source of flow, and localized conditions which may make plugging or sealing of the spring possible.
2. Evaluate hydraulic conditions at polluting springs to determine whether diversion or isolation by increasing the overflow "pressure head" may be effective in stopping the spring flow.
3. Extensive work has been done on locating the springs with highly mineralized water in the various states of the region. Research is needed to determine the extent of any pollution to the ground water which these springs might be causing. Then ways should be sought to eliminate that source of pollution.

EVAPO-TRANSPIRATION OF NATIVE VEGETATION

The prospect of salvaging valuable water now being wasted by comparatively useless vegetation, while at the same time decreasing the accompanying mineralization of the water supply, has provided an attractive goal for many engineers and scientists. Various programs of vegetation eradication have been attempted with very limited success. The growth usually returns within a short period of time. Erosion resulting during the eradication period has created serious soil loss problems in the eradication areas and sedimentation problems in the nearby stream channels. Nevertheless, the authors believe that research along the following lines could be fruitful:

1. Development and evaluation of replacement vegetation having lower water use characteristics than the water-loving phreatophytes.
2. Investigation of the possibilities of leveling areas of phreatophyte growth and utilizing the areas for agricultural production. Such a program should involve consideration of subsidization because of the intermittent flooding, poor soil conditions and low yield potential.

INJECTION WELLS FOR WASTE DISPOSAL

The use of injection wells to dispose of wastes is a rapidly-growing practice in the U.S. Much of this use in uncontrolled and done without any public record or knowledge. Pollution possibilities from these practices are staggering. It is likely that legislation is needed to establish control procedures.

Research ideas which may be helpful are:

1. Conduct a detailed investigation to determine, in each of the states, deep well injection policies, controls, practices and existing injection programs (including volume and quality of all injection material).
2. Conduct geological and geophysical investigations at existing and potential injection sites to evaluate possible aquifer interconnections, hydrostatic pressure and storage capabilities--such investigations to serve as a basis for establishing policies for the use of injection wells as a means of waste disposal.
3. Encourage states to develop means of prohibiting deep well injection where it will decrease the ground water quality.
4. Develop guide lines for controlling the use of injection wells for waste disposal.
5. Make a study of several injection well operations under various aquifer conditions to determine whether or not the ground water is being polluted by the disposal of various waste materials.

FERTILIZATION OF AGRICULTURAL LANDS

There are many elements necessary for plant growth. In addition to the carbon, hydrogen and oxygen taken from air and water, the plants require nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, iron, manganese, Zinc, copper, boron, molybdenum and a number of other "minor" elements. Some of these elements are required in only minute amounts and are usually present naturally in most soils, but three--nitrogen, potassium, and phosphorus--are usually added in great amounts. Research to date has indicated that nitrates go into solution as water is added to the soil, and often move through the soil into the ground water. Phosphates appear to be adsorbed on the soil particles, and do not move into the ground water. Potassium is not known to cause any problem. More research is needed, and the following ideas are suggested:

1. Investigate the movement through the soil and the fate of various fertilizer additives--nitrogen, phosphorous, potassium, or others that could cause a ground water pollution problem.

2. Evaluate various fertilizer application and management practices especially to include the time of fertilizer application as related to the time of heaviest water application in order to minimize leaching away of fertilizer elements.

3. Investigate relative ground water pollution under programs utilizing slow-release fertilizers now available or others that may be developed.

LAND DISPOSAL OF WASTES - MUNICIPAL OR INDUSTRIAL

Many municipal and industrial wastes are disposed of by spreading on the ground surface--in both liquid and solid form. Procedures governing such spreading and research to evaluate pollution hazards are needed. Research suggestions are as follows:

1. Evaluate ground water pollution potential of land disposal practices, especially including the ultimate fate of toxic materials or any potential pollutant which may be involved.

2. Develop guide lines defining characteristics of good land disposal sites.

3. Develop management practices which may permit land disposal of certain wastes, including "rest" periods for disposal areas and cultivation practices in disposal areas.

SEEPAGE OF POLLUTED SURFACE WATERS

Whenever polluted surface waters seep into the ground they constitute a potential ground water pollution hazard. Needs in this category are essentially preventive--prevention of the pollution of surface waters, or management of them to prevent infiltration.

URBAN RUNOFF

Storm drainage from urban areas inevitably picks up various pollutants. Degradable organic pollutants or bacteria are not usually a problem to the ground water since they are not usually transmitted through the soil mantle. Toxic materials and phenols could be a problem. Salt used to melt roadway ice and snow in winter constitutes a serious potential problem--especially in arid regions where mineralization is a primary cause of water quality degradation. Research ideas are as follows:

1. Study the winter urban runoff, in areas where salt is used on roadways, to evaluate mineralization of the groundwater by such practices.

2. Develop guide lines relating to treatment of urban waste waters which may be used for ground water replenishment.

3. Evaluate the extent of ground water pollution from urban developments in mountain areas.

CONNATE WATER WITHDRAWAL

Connate water withdrawal may result when a fresh ground water aquifer is over-developed. Efforts to prevent ground water pollution by this means should concentrate on a determination of aquifer development limits. Research along these lines is suggested:

1. Study all producing ground water aquifers to determine storage and useable available water so that the development limits may be determined before over-development occurs.

MINING ACTIVITIES

Most mining activities intercept ground water. In most mines the water quality is probably not affected appreciably. However, in mines where pyritic formations are exposed to air and water, sulfuric acid drainage may result. Research and investigation suggestions are as follows:

1. Investigate the characteristics of drainage from mines wherever it exists in appreciable amounts.

2. Evaluate ground water pollution potential of the mine drainage to determine whether treatment of the drainage water is necessary before it is permitted to mix with natural waters.

3. Evaluate mining practices to determine methods which might be utilized to control natural drainage from the mine after it becomes inactive.

AQUIFER INTERCHANGE

Interchange of ground water from one aquifer to another is usually the result of improper drilling practices. Control of drilling practices in all states should include provisions to prohibit promiscuous perforation of well casings at many different aquifers in the same well which so often occurs. Suggestions for research are as follows:

1. Develop policies and procedures which will result in well drilling methods that will help assure that there is neither a planned nor an inadvertent interchange of waters between different aquifers.
2. Develop procedures by which evaluation of intermixing of aquifers in existing wells can be made, followed by selective sealing of some aquifers or complete sealing of the entire well if necessary to protect water quality. This would be especially important for abandoned wells.

MINERALIZATION FROM SOLUBLE AQUIFERS

Since this is primarily a natural process, it is not likely that corrective or preventative measures can be taken. As competition for water increases polluted waters from these sources may need to be made useable by some demineralization process.

CROP RESIDUES AND DEAD ANIMALS

Crop residues and dead animals constitute a potential source of ground water pollution, particularly from nitrates resulting from the decomposition of organic matter. Research ideas are as follows:

1. Study actual ground water pollution adjacent to areas of dead animal or concentrated crop residue disposal to determine pollution potential from such sources.
2. Evaluate methods of disposal of dead animals, such as poultry, so that ground water quality may be protected. Methods of disposal may include (a) grinding and disposal with manure (b) grinding and utilization as animal feed, and (c) incineration.
3. Develop regulatory controls, especially for disposal of dead animals by burial underground, so that ground water quality may be protected.

PESTICIDE RESIDUES

Continued developments in the various pesticides results in rapid changes in the water quality effects. Pesticides of today are in great variety and application compared with those of even a few years ago. The future will likely bring even greater changes. Research ideas are as follows:

1. Continued investigation of new and existing varieties of pesticides to determine their ultimate fate in the ground and particularly their effect on ground water quality.

2. Development of pesticides--insecticides, herbicides, and soil fumigants which will not be environmental pollutants.

LAND SUBSIDENCE EFFECTS OF WATER QUALITY

In Section VI, it was reported that land subsidence may be a possible cause of the occurrence of arsenic in the ground water. Research should be conducted in the areas of land subsidence to determine whether such a relationship does exist or not.

SEWER LEAKAGE

Many old sewer systems, constructed before the development of satisfactory joint systems, represent potential sources of ground water contamination. Biological contamination has not been known to move any great distance underground, and pollution of this type would, therefore, usually be a localized problem. Investigation and evaluation of suspected sewers may be worthwhile in some instances but future control should likely relate to the use of leak-proof jointing systems. No particular research effort is indicated.

THERMAL POLLUTION

Cooling processes related to electrical energy generation or any industrial plant may have an appreciable effect on ground water temperatures. Any operation which has this potential should be carefully evaluated to determine present and long-range effects on ground water quality. Research is also needed to evaluate the effects of elevated ground water temperatures on the degradation of various waste products which may exist underground. Such degradation could have the effect of releasing toxic substances to the ground water.

RADIOACTIVITY

Radioactivity, whether resulting from natural deposits, from mining or ore processing, or from disposal of radioactive wastes is a potential water pollution danger. Prevention at the source, rather than corrective research, would be the most desirable control.

RECREATIONAL ACTIVITY

Recreational activities are resulting in serious pollution of surface waters, and there is potential hazard to ground waters in affected areas. Programs to protect surface waters will probably correct any ground water problems, and research aimed particularly at ground water quality is not required at this time. Monitoring of water quality in areas of potential problem should be carried out.

SECTION VIII

ACKNOWLEDGEMENTS

Many agencies and individuals have given assistance in the compilation of reports, publications, and personal interviews which were used as a basis for this report. During the data-gathering phase many hundreds of reports were reviewed and many public officials were interviewed in the four states included in the project area.

Among the federal agencies, the U.S. Geological Survey and the U.S. Bureau of Reclamation have provided much valuable information. The Regional Offices of the U.S. Bureau of Reclamation in Salt Lake City, Boulder City and Sacramento have provided many reports containing valuable information. The District offices of the U.S. Geological Survey in Salt Lake City, Carson City, Palo Alto and Tucson have provided a great number of reports, many of which are "open-file" unpublished reports, which have been of great assistance in the project.

The various state Water Quality Control offices have been very cooperative and helpful to us. Many County and District officers have provided information which has been invaluable in the writing of this report.

Nearly one hundred individuals, staff members of the agencies mentioned above have provided cooperative assistance and reference material. Because of the great number, no attempt is made here to give individual credit, but their cooperation is gratefully acknowledged.

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SECTION X

GLOSSARY OF TERMS, ABBREVIATIONS AND SYMBOLS

Advanced Waste Treatment - In sewage, the additional treatment of effluent beyond that of secondary treatment, in order to obtain a very high quality of effluent. Usually includes nutrient removal.

Alkalization - The process by which exchangeable sodium accumulated on the soil colloids and the soil becomes more alkaline in reaction.

Aquifer - A geologic formation which contains water and has the capability of transmitting it from one point to another in quantity to permit economic development.

Artificial Recharge - The addition of water to the ground-water reservoir by activities of man, such as irrigation or induced infiltration from streams, wells, or spreading basins.

Beneficial Use of Water - The use of water for any purpose from which benefits are derived, such as domestic, irrigation, or industrial supply, power development, or recreation.

Biochemical Oxygen Demand (B.O.D.) - The quantity of oxygen utilized primarily in the biochemical oxidation of organic matter in a specified time and at a specified temperature. The time and temperature are usually five days and 20°C.

Brackish Water - Water containing dissolved minerals in excess of acceptable normal municipal, domestic, and irrigation standards, but less than that of sea water.

Cenozoic Age - Division of geological history from the beginning of the Tertiary (first period in the Cenozoic Era) to the present.

cfs - Abbreviation for cubic feet per second.

Chemical Water Quality - Reflects the spectrum and level of concentration of dissolved chemicals in a water supply.

Closed Basin - A basin is considered closed with respect to surface flow if its topography prevents the occurrence of visible outflow. It is closed hydrologically if neither surface nor underground outflow can occur.

Confined Aquifer - An aquifer which is bounded above and below by formations of impermeable or relatively impermeable material.

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Concentration - The quantity of dissolved materials in a unit volume or weight of water. In this report concentration is expressed in milligrams per liter, parts per million, equivalents per million, specific electrical conductance in micromhos per cm, and tons per acre foot.

Connate Water - Sea water held in the interstices of sedimentary deposits and sealed in by the deposition of overlying beds.

Conservative Constituents - Materials carried in the hydrologic system which, on a class basis, do not interact with the chemical, physical, or biological elements of the environment to a significant extent. This classification includes broad groups of materials such as total dissolved solids because net conservatism is maintained even though such interactions as ion exchange take place with the group.

Consumptive Use (Water) - The sum of the quantity of water used by vegetative growth in transpiration or building of plant tissue and the quantity evaporated from adjacent soil or plant surfaces in a given specified time. Also referred to as Evapotranspiration.

Deep Percolation - In a geologic sense, the percolation downward of water by leakage through the geologic formation. In hydrology, it is the percolation downward of water past the lower limit of the root zone.

Degradable - Capable of being decomposed, deteriorated, or decayed into simpler forms with characteristics different from the original. Also referred to as biodegradable.

Degradation of Water Quality - Decrease in water quality due to increased concentration of any substance classified as a pollutant.

Demineralization - The process of removing the mineral salts from water.

Depletion (Ground-Water) - The withdrawal of water from a ground-water source at a rate greater than its rate of replenishment, usually over an extended period of several years.

Dissolved Oxygen - The amount of free (not chemically combined) oxygen in water. Usually expressed in milligrams per liter.

Dissolved Solids - Chemicals in true solution.

Drawdown - The magnitude of lowering of the surface of a body of water or of its piezometric surface as a result of withdrawal or the release of water therefrom.

Effluent Stream - A stream which intersects the water table and receives flow from ground water.

Eutrophication - The process of overfertilization of a body of water by nutrients which produces more organic matter than the self-purification processes can overcome.

Evapotranspiration - See Consumptive Use.

Flood Plain - Land bordering a stream and which receives overbank flow.

Fluvial Sediment - River or stream sediment deposits.

Geomorphic Province - A region in which the majority of land features have a degree of similarity as to its origin and development.

Ground Water - Underground water that is in the zone of saturation.

Ground Water Basin - A ground water reservoir together with all the overlying land surface and the underlying aquifers that contribute water to the reservoir. In some cases, the boundaries of successively deeper aquifers may differ in a way that creates difficulty in defining the limits of the basin.

Ground Water Mining - See Depletion (Ground Water).

Ground Water Overdraft - See Overdraft.

Ground Water Recharge - Inflow to a ground water reservoir.

Ground Water Reservoir - An aquifer or aquifer system in which ground water is stored. The water may be placed in the aquifer by artificial or natural means.

Ground Water Storage Capacity - The reservoir space contained in a given volume of deposits. Under optimum conditions of use, the usable ground water storage capacity volume of water that can be alternately extracted and replaced in the deposit, within specified economic limitations.

Hydrographic Study Area - An area of hydrological and climatological similarity so subdivided for study purposes.

Hydrologic Budget - An accounting of all inflow to, outflow from, and changes in storage within a hydrologic unit such as a drainage basin, soil zone, aquifer, lake, or project area.

Hydrologic Cycle - The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.

Igneous Rock - Rock formed by volcanic action or great heat.

Infiltration - The process whereby water passes through an interface, such as from air to soil or between two soil horizons.

Land Subsidence - The lowering of the natural land surface in response to: earth movements; lowering of fluid pressure; removal of underlying supporting material by mining or solution of solids, either artifically or from natural causes; compaction due to wetting (Hydrocompaction); oxidation of organic matter in soils; or added load on the land surface.

Mesophyte - A plant that grows under medium or usual conditions of atmospheric moisture supply as distinguished from one which grows under dry or desert conditions (xerophytes) or very wet conditions (hydrophytes). See Phreatophyte.

Mesozoic Age - The geological era after the Paleozoic and before the Cenozoic eras.

Metamorphic Rock - Rock formed by a change in structure due to pressure, heat, chemical action, etc.

mg/l - Abbreviation for milligrams per liter.

Milligrams Per Liter - The weight in milligrams of any substance contained in one liter of liquid. Approximately equivalent to parts per million.

Mineralization - The process of accumulation of mineral elements and/or compounds in soil or water. See also Salinization.

Mining of Ground Water - See Depletion (Ground Water).

Nutrients - Compounds of nitrogen, phosphorus, and other elements essential for plant growth. (These may have an adverse effect on water quality).

Overdraft - The amount by which pumpage of ground water exceeds the safe yield of the ground water aquifer or basin.

Parts Per Million (ppm) - Parts by weight in a million weight units. Approximately equivalent to milligrams per liter.

Perched Ground Water - Ground water supported by a zone of material of low permeability and located above an underlying main body of ground water with which it is not hydrostatically connected.

Percolation - The movement of water within a porous medium such as soil.

Perennial Yield (Ground Water) - The amount of usable water of a ground water reservoir that can be withdrawn and consumed economically each year for an indefinite period of time. It cannot exceed the natural recharge to that ground water reservoir.

Permeability - The property of a material which permits appreciable movement of water through it when actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.

Pesticides - Chemical compounds used for the control of undesirable plants, animals, or insects. The term includes insecticides, weed killers, rodent poisons, nematode poisons, fungicides, and growth regulators.

pH (Hydrogen Ion Concentration) - Measure of acidity or alkalinity of water. Distilled water, which is neutral, has a pH value of 7; values above 7 indicate the pressure of alkalies, while those below 7 indicate acids.

Phreatophyte - A plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe. See Mesophyte.

Playas - Flat floored bottom of an undrained desert basin.

Pollutants - Substances that may become dissolved, suspended, absorbed, or otherwise contained in water, that impair its usefulness.

Pollution - The presence of any substance (organic, inorganic, biological, thermal, or radiological) in water at intensity levels which tend to impair, degrade, or adversely affect its quality or usefulness for a specific purpose.

Primary Treatment - In sewage, the removal from sewage of larger solids by screening, and of more finely divided solids by sedimentation.

Recharge - See Ground Water Recharge.

Recharge Basin - A basin provided to increase infiltration for the purpose of replenishing ground water supply.

Return Flow - That part of a diverted flow which is not consumptively used and which returns to a source of supply (surface or underground).

Safe Ground-Water Yield - The annual pumpage that can be sustained without permanent change in ground water storage, or without short-term changes in storage.

Saline Water - Water containing dissolved salts. See also Brackish Water.

Salinity - Salt content concentration of dissolved mineral salts in water or soil.

Salinization - The process of accumulation of soluble salts in soil or water. See also Mineralization.

Salt Balance - A condition in which specific or total dissolved solids removed from a specified field, stratigraphic zone, political area, or drainage basin equals the comparable dissolved solids added to that location from all outside sources during a specified period of time.

Salt Water Barrier - A physical facility or method of operation designed to prevent the intrusion of salt water into a body of fresh water. In underground water management a barrier may be created by injection of relatively fresh water to create a hydraulic barrier against salt water intrusion.

Salt Water Intrusion - The invasion of a body of fresh water by salt water. It can occur either in surface or ground water bodies.

Secondary Treatment - In sewage, the further purification of the effluent from primary treatment by trickling filters, activated sludge units, oxidation ponds, or other means.

Seepage - The gradual movement of a fluid into, through, or out of a porous medium.

Sewage Plant Effluent - The outflow from a sewage treatment plant.

Suspended Solids - Solids which are not in true solution and which can be removed by filtration.

Sustained Yield - Achievement and maintenance, in perpetuity, of a high-level annual or regular periodic output or harvest of the various renewable land and water resources.

Total Dissolved Solids (TDS) - The total dissolved solids in water, usually expressed in milligrams per liter (mg/l) or parts per million (ppm).

Toxicity - The state or degree of being poisonous.

Turbidity - Level of concentration of suspended particulate matter which can be removed through filtration.

USBR - Abbreviation of United States Bureau of Reclamation, Department of Interior.

USGS - Abbreviation of United States Geological Survey, Department of Interior.

USGS - WSP - Abbreviation for United States Geological Survey, Water Supply Paper.

Waste Water Reclamation - The process of treating salvaged water from municipal, industrial, or agricultural waste water sources for beneficial uses, whether by means or special facilities or through natural processes.

Water Desalination - The removal of dissolved salts from a saline water supply.

Water Quality - A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water Right - A legally protected right to take possession of water occurring in a water supply and to divert that water and put it to beneficial use.

Water Table - The upper supply of a zone of saturation, except where that surface is confined by an impermeable body.

SECTION XI

APPENDIX A

WATER QUALITY STANDARDS

The extent of undesirability of a given level of pollution in water is dependent upon the use or intended use of the water. Standards of quality of water used for domestic water supply have been established by the National Technical Advisory Committee on Water Quality Criteria (238), and the U.S. Public Health Service (91). Tables A-1 and A-2, presented herein, are taken from their reports.

Various agencies have set standards of quality for waters used for other purposes. Table A-3 gives standards for livestock watering as reported by McGauhey (239). Tables A-4, A-5 and A-6 present irrigation water quality standards as suggested by the Economic Research Service (240). Table A-7 gives standards for water used in various industrial processes as reported by the American Society for Testing Materials (241).

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Table A-1. Surface Water Criteria for Public Water Supplies (238)

Constituent or Characteristic	Permissible[a] Criteria	Desirable[b] Criteria
Physical:		
Color (color units)	75	< 10
Microbiological:		
Coliform organisms	10,000/100 ml[c]	< 100/100 ml[c]
Fecal coliforms	2,000/100 ml[c]	< 20/100 ml[c]
Inorganic Chemicals:	(mg/l)	(mg/l)
Ammonia	0.5 (as N)	< 0.01
Arsenic	0.05	Absent
Barium	1.0	Absent
Boron	1.0	Absent
Cadmium	0.01	Absent
Chloride	250	< 25
Chromium, hexavalent	0.05	Absent
Copper	1.0	Virtually Absent
Dissolved Oxygen	4 (monthly mean) 3 (indiv. sample)	Near Saturation
Iron (filterable)	0.3	Virtually Absent
Lead	0.05	Absent
Manganese (filterable)	0.05	Absent
Nitrates plus nitrites	10 (as N)	Virtually Absent
pH (range)	6.0 to 8.5	Variable
Selenium	0.01	Absent
Silver	0.05	Absent
Sulfate	250	< 50
Total dissolved solids, (filterable residue)	500	< 200
Uranyl ion	5	Absent
Zinc	5	Virtually Absent

[a] Permissible criteria--Those characteristics and concentrations of substances in raw surface waters which will allow the production of a safe, clear, potable, aesthetically pleasing, and acceptable public water supply which meets the limits of Drinking Water Standards after treatment.

[b] Desirable criteria--Those characteristics and concentrations of substances in the raw surface waters which represent high-quality water in all respects for use as public water supplies. Water meeting these criteria can be treated in the defined plants with greater factors of safety or at less cost than is possible with waters meeting permissible criteria.

Table A-1 (cont'd) Surface Water Criteria for Public Water Supplies(238)

Constituent or Characteristic	Permissible[a] Criteria	Desirable[b] Criteria
Organic Chemicals:	(mg/l)	(mg/l)
Carbon chloroform extract(CCE)	0.15	<0.04
Cyanide	0.20	Absent
Methylene blue active substnaces	0.5	Virtually Absent
Oil and Grease	Virtually Absent	Absent
Pesticides:		
Aldrin	0.017	Absent
Chlordane	0.003	Absent
DDT	0.042	Absent
Dieldrin	0.017	Absent
Endrin	0.001	Absent
Heptachlor	0.018	Absent
Heptachlor epoxide	0.018	Absent
Lindane	0.056	Absent
Mathoxychlor	0.035	Absent
Organic phosphates plus Carbamates	0.1[d]	Absent
Toxaphene	0.005	Absent
Herbicides:		
2, 4-D plus 2, 4, 5-T plus 2, 4, 5-TP	0.1	Absent
Phenols	0.001	Absent
Radioactivity:	(pc/l)	(pc/l)
Gross beta	1,000	<100
Radium-226	3	<1
Strontium-90	10	<2

[a] See Previous page

[b] See Previous page

[c] Microbiological limits are monthly arithmetic averages based upon an adequate number of samples. Total coliform limit may be relaxed if fecal concentration does not exceed the specified limit.

[d] Expressed as parathion in cholinesterase inhibition. It may be necessary to resort to even lower concentrations for some compounds or mixtures.

Table A-2. Chemical Standards of Drinking Water (91).

Category A -- Maximum allowable concentrations where other more suitable Supplies are, or can be made available:

Substance	Concentration in mg/1
Alkyl Benzene Sulfonate (ABS)	0.5
Arsenic (As)	0.01
Chloride (Cl)	250
Copper (Cu)	1
Carbon Chloroform Extract (CCE)	0.2
Cyanide (CN)	0.01
Iron (Fe)	0.3
Manganese (Mn_a)	0.05
Nitrate (NO_3)	45
Phenols	0.001
Sulfate (SO_4)	250
Total Dissolved Solids (TDS)	500
Zinc Zn)	5

Category B -- Maximum concentrations which shall constitute grounds for outright rejection of the supply:

Substnace	Concentration in mg/1
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Hexavalent) (Cr^{+6})	0.05
Cyanide (CN)	0.2
Fluoride (F)	0.6 to 1.7[b]
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05

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[a] In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

[b] Varies with water temperature.

Table A-3. Guides to the Quality of Water for Livestock (239)

Quality Factor mg/l	Threshold[a] Concentration	Limiting[b] Concentration
Total Dissolved Solids (TDS)[c]	2500	5000
Cadmium	5	-
Calcium	500	1000
Magnesium	250	500
Sodium	1000	2000
Arsenic	1	-
Bicarbonate	500	500
Chloride	1500	3000
Fluoride	1	6
Nitrate as NO_3	200	400
Nitrite	none	none
Sulfate	500	1000
Range of pH	6.0 to 8.5	5.6 to 9.0

[a] Threshold values represent concentrations at which poultry or sensitive animals might show slight effects from prolonged use of water. Lower concentrations are of little or no concern.

[b] Limiting concentrations based on interim criteris, South Africa studies. Animals in lacatation or production might show definite adverse reaction.

[c] Total magnesium compounds plus sodium sulfate should not exceed 50 per cent of the total dissolved solids.

Table A-4. Suggested guidelines for Salinity in Irrigation Water (240)

Crop Response	TDS in mg/l	EC[a]
Water for which no detrimental effects will usually be noticed	less than 500	less than 0.75
Water which can have detrimental effects on sensitive crops	500-1000	0.75-1.50
Water that may have adverse effects on many crops and requiring careful management practices	1000-2000	1.50-3.00
Water that can be used for salt-tolerant plants on permeable soils with careful management practices	2000-5000	3.00-7.50

[a] Electrical Conductivity expressed in millimhos per centimeter

Table A-5. Trace Element Tolerances for Irrigation Water (240)

Element	For Water Used Continuously on All Soils mg/l	For Short-term Use on Fine Textured Soils Only mg/l
Aluminum	1.0	20.0
Arsenic	1.0	10.0
Beryllium	0.5	1.0
Boron	0.75	2.0
Cadmium	0.005	0.05
Chromium	5.0	20.0
Cobalt	0.2	10.0
Copper	0.2	5.0
Lead	5.0	20.0
Lithium	5.0	5.0
Manganese	2.0	20.0
Molybdenum	0.005	0.05
Nickel	0.5	2.0
Selenium	0.05	0.05
Vanadium	10.0	10.0
Zinc	5.0	10.0

Table A-6. Levels of Herbicides in Irrigation Water at Which Crop Injury Has Been Observed. (240)

Herbicide	Crop Injury Threshold in Irrigation Water, expressed in mg/l
Acrolein	Flood or Furrow: beans - 60, corn-60, cotton-80, soybeans-20, sugar beets-60. Sprinkler: corn-60, soybeans-15, sugar beets-15.
Aromatic Solvents (Xylene)	Alfalfa >1600, beans-1200, carrots-1600, corn-3000, cotton-1600, grain sorghum >800, oats-2400, potatoes-1300, wheat >1200.
Copper Sulfate	Apparently, above concentrations used for weed control.
Amitrole-T	Beets (rutabaga) >3.5, corn >3.5.
Dalapon	Beets >7.0, corn <0.35
Dequat	Beans-5.0, corn 125.0.
Endothall Na and K salts	Corn-25, field beans <1.0, alfalfa >10.0.
Dimethylamines	Corn >25, soybeans >25, sugar beets-25.
2, 4-D	Field Beans >3.5 <10, grapes-0.7-1.5, sugar beets-3.5.
Dichlobenil	Alfalfa-10, corn >10, soybeans-1.0, sugar beets-1.0-10.
Fenac	Alfalfa-1.0, corn-10, soybeans-0.1, sugar beets-0.1-10.
Picloram	Corn >10, field beans-0.1, sugar beets <1.0.

Note: Where the symbol " >" is used, the concentrations in water cause no injury. Data are for furrow irrigation unless otherwise specified.

Table A-7. Preferred limits for Several Criteria of Water for Use in Industrial Processes (241).

Process	Turbidity Max. ppm	pH		TDS Max. mg/l
		Min.	Max.	
Aluminum (hydrate Wash)				low
Baking	10			
Boiler Feed:				
0 to 150 psi	80	8.0		3000
150 to 250 psi	40	8.4		1500
250 to 400 psi	5	9.0		2500
400 to 1000 psi	2	9.6		50
Over 1000 psi				0.5
Brewing	10	6.5	7.0	1500
Carbonated beverages	2			
Confectionery		7.0		100
Dairy				500
Electroplating and finishing, rinse				low
Fermentation	low			
Food Canning and Freezing	10	7.5		850
Food Processing, general	10			
Ice Manufacturing				170 to 1300
Laundering		6.0	6.8	
Oil Well Flooding		7.0		
Photographic process	low			
Pulp and Paper:				
Groundwood paper	50			500
Soda and Sulfate pulp	25			250
Kraft paper, bleached	40			300
Kraft paper, unbleached	100			500
Fine paper	10			200
Sugar Manufacture				low
Tanning Operations	20	6.0	8.0	
Textile Manufacture	0.3			

Note: The values in this table are taken from summaries in the comprehensive review by McKee and Wolf, cited in the ASTM report (241), and are presented here only as a general guide. They should be used only after study of the original references cited in the ASTM report.

SECTION XII

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An investigation to determine the ground water pollution problems which exist in the states of Arizona, California, Nevada, and Utah was conducted. Data were obtained through an extensive review of the literature and through interviews with engineers, scientists, and governmental officials concerned with water pollution in the four states of the project area.

Mineralization of ground water is the most prevalent factor in the degradation of ground water quality in the project area. Large quantities of ground water in each of the four states are undesirable for many uses because of excessive mineralization. Much of the mineralization of ground water is a result of natural processes. Some is caused by man's activities--irrigation, oil field brine disposal, and over-pumping of aquifers are common causes of mineralization. Usually the degradation is caused by an excess of total dissolved solids, but at some locations, specific toxic substances are also found in the ground water. Of the various forms of pollution of ground water caused by man's activities, nitrate is probably most prevalent in the project area.

A listing of conditions causing ground water pollution in the project area is included in the report.

17a. Descriptors

*Groundwater, *water pollution, groundwater basins, water resources, salinity

17b. Identifiers

*Southwest United States, Arizona, California, Nevada, Utah

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